When predators go missing – rise of the herbivores

Native mammal herbivore imbalance and the predator-prey ecology of southeast Australia

Jeff Yugovic

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Jeff Yugovic, June 2017

Summary

Ecosystems are dominated and shaped by predators. Predators form food chains which interlink to become the food web which is the basis of much biodiversity.

Top predators control populations of smaller mesopredators and herbivores, preventing them from monopolising or destroying resources needed by many species.

Predator pressure stabilises ecosystems but can be prevented by human agency. In southeast Australia several native mammal herbivores and omnivores respond by increasing to severely damage ecosystems. These include red, eastern and western grey kangaroos (ground layer loss), black wallaby (shrub loss), koala, brushtail and ringtail possums (tree canopy loss) and swamp rat (orchid loss). Several novel herbivores including rabbits also undergo herbivore release and imbalance without predator pressure.

Major herbivore imbalances inside predator exclosures show that novel ground predators normally control native and novel herbivores in more human-modified areas due to the widespread loss of native predators. Together with any remaining native predators they are essential in order to keep novel bushland ecosystems relatively healthy and balanced.

The dingo/dog is the partial replacement top predator for humans, thylacines and devils but is now rare or absent over large areas. The fox and cat are widespread partial replacement mesopredators for quolls, goannas, pythons and other predators. However the novel predators compete with or prey on several native predators, and the fox without its top predator dingo appears to undergo mesopredator release which increases its impact on threatened fauna.

Maintaining a balance between predators, herbivores and habitats for all species involves managing predator and herbivore pressure with sound management practices.

The predator-prey or trophic model of ecosystem function consists of site-specific food chains linked in a food web. Based on predation, an essential process, it is predictive and effective as a management tool. The model can be applied to understand healthy systems, adjust predator and herbivore pressure in modified systems, and develop policies and interventions.

A natural ecological logic or trophic paradigm in which predators control herbivores is most appropriate. The fantasy school of ecology in which the alien predators must be killed so the native fauna can live and reproduce in peace only means ecological damage if there are no other predators. That’s not the way ecology works and never has been. We have to manage the actual ecosystem, not an imagined predator-free system that never existed. Ideology, silo mentality and vested interest should not override conservation biology.

www.spiffa.org/do-ecosystems-need-top-predators
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Introduction

Ecosystems are dominated and shaped by predators. Predators form food chains which interlink to become the food web which is the basis of much biodiversity. Carnivores are predators of herbivores and herbivores are predators of plants. Predators, competition, stress and isolation are major drivers in the evolution of species and ecosystems.

Top predators control populations of smaller mesopredators and herbivores, preventing them from monopolising or destroying resources needed by many species.

Predator pressure stabilises ecosystems but can be prevented by human agency. When top predators are eliminated entire tree canopies can be lost to koalas or monkeys and leafcutter ants and whole areas can be denuded by rabbits or kangaroos. Mesopredators such as raccoons or foxes are more abundant and take more small fauna.

Loss of native vertebrate predators in regions occupied by humans is a consistent global pattern. In southeast Australia most of the native terrestrial top predators and mammal mesopredators are extinct or their populations are reduced and fragmented. Their problems are compounded by having competitive human-adapted novel mesopredators: the fox and cat.

Here we explore the role of vertebrate top predators and mesopredators in regulating terrestrial ecosystems by controlling native mammal herbivores in southeast Australia.

The ecological need for vertebrate predators applies to most or all terrestrial ecosystems in the region, both natural and modified, since every area without its relevant predators has undergone ecological malfunction.

In the widespread modified ecosystems where native ground and arboreal predators are effectively extinct, the novel mesopredators now have a strong stabilising effect. Here they partly replace the original predators, and despite their toll on threatened fauna in some areas, they continue the necessary ecological function of herbivore control everywhere.

Novel predators are controlled because they prey on native fauna, but there is something more fundamental to conservation than killing novel predators, something ecological: around the world, ecosystems where vertebrate predators are eliminated by humans are worse off from vertebrate herbivore imbalance. In southeast Australia, this has become clear in recent years since every large novel predator exclosure in the region has experienced some form of major herbivore imbalance, be it from rabbits to wallabies or kangaroos.

Meanwhile land managers are increasingly dealing with the ecosystem consequences of mass native predator extinction in areas such as the Mornington Peninsula. They are getting on with practical issues such as saving woodlands from the catastrophic effects of ringtail possum overpopulation and even see redeeming features in the novel predators.

The extent to which predators prevent native mammal herbivore release and imbalance elsewhere in Australia is not clear, partly because mass predator extinction is restricted to the southeast region – fortunately. But the affected areas do provide a fascinating insight into ecology everywhere by revealing the pervasive influence of predation as a law of nature.
**Predator-prey ecology**

Predator-prey or trophic ecology is the study of the structure of feeding relationships among organisms in an ecosystem. The founder of modern trophic ecology is Charles Elton who in 1927 proposed a food cycle model in which organisms occupy (trophic) levels in a food pyramid. He correctly predicted that elimination of predators would lead to deer overpopulation after the mule deer irruption and collapse on the Kaibab Plateau in Arizona.

In 1960 Nelson Hairston, Frederick Smith and Lawrence Slobodkin proposed that predators keep herbivores from eating most of the Earth’s vegetation – the green world hypothesis.

Robert Paine identified the role of keystone species in 1969. He found that an ecosystem may undergo a dramatic shift if a keystone species is removed, even though that species forms only a small part of the ecosystem biomass. A keystone species benefits other species by definition. Paine proposed that ecosystems are top-down controlled by keystone predators which maintain diversity by limiting prey populations and preventing resource monopoly.

A large body of evidence indicates that top-down predator control of mesopredators and herbivores maintains ecosystem function and biodiversity globally. Many large-scale trophic cascades in which predators limit herbivores and so protect plants and their dependent species have been seen in terrestrial and freshwater and marine ecosystems. The loss of large apex carnivores ‘may be humankind’s most pervasive influence on nature’.

Predators influence their prey through (a) control of population size – numbers, (b) regulation of population – stability or fluctuation in numbers, (c) behaviour – predator avoidance, and (d) natural selection which ‘favours more effective predators and more evasive prey’.

In simple models of ecosystems, predators and their prey undergo regular predator-prey cycles. The predator-prey cycle is governed by a pair of differential equations, the Lotka-Volterra equations:

\[
\frac{dx}{dt} = \alpha x - \beta x y \\
\frac{dy}{dt} = \delta x y - \gamma y
\]

**Figure 1. Predator-prey cycle**

The LV equations assume a one-predator-one-prey system which is seldom the case. In complex systems, simple predator-prey cycles are dampened by alternative predator-prey interactions such as prey switching when a prey species becomes rare. They also assume an unlimited food supply for the prey. The cycle ceases if the predators go missing: the food resource is destroyed by the prey species which then crashes. This is relevant to management.
Graeme Caughley in 1981 proposed a model of animal overabundance with four classes:  
1. threats to human life or livelihood  
2. depression of the density of favoured species  
3. decline in body condition and reproduction  
4. loss of equilibrium between plants and animals  

The model includes ecological and non-ecological values, the last class being fully ecological and relevant to efforts to protect and manage natural ecosystems. The ecological consequences of class 4 overpopulation are potentially major and long-term.  

Why herbivores don’t usually increase to levels that would devastate vegetation and cause their own collapse has been subject to debate. Are their populations limited by predators – top-down control, or are they limited by resource supply – bottom-up control? Both controls were found to operate in a global meta-analysis of population responses of small mammals to food supply and predators, depending on species. Either or both controls operate on each herbivore population. Field experiments can best answer these questions.  

Predator exclosures are informal field experiments in predator-prey ecology. Experience with exclosures in southeast Australia indicates that top-down forces predominate with medium and large native and novel mammals: predators are preventing overabundance.
Native predators

Southeast Australia has a diverse assemblage of high trophic level native vertebrate predators which includes mammals, birds and reptiles.\textsuperscript{18}

Top predators

The native or original (pre-European) terrestrial top predators include the following:

<table>
<thead>
<tr>
<th>Table 1. Major native or original top predators of southeast Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species</strong></td>
</tr>
<tr>
<td>Human</td>
</tr>
<tr>
<td><em>Homo sapiens</em></td>
</tr>
<tr>
<td>Thylacinus cynocephalus</td>
</tr>
<tr>
<td>Dingo</td>
</tr>
<tr>
<td><em>Canis lupus dingo</em> (novel)</td>
</tr>
<tr>
<td>Tasmanian devil</td>
</tr>
<tr>
<td><em>Sarcophilus harrisii</em></td>
</tr>
<tr>
<td>Wedge-tailed eagle</td>
</tr>
<tr>
<td><em>Aquila audax</em></td>
</tr>
<tr>
<td>Powerful owl</td>
</tr>
<tr>
<td><em>Ninox strenua</em></td>
</tr>
<tr>
<td>Grey goshawk</td>
</tr>
<tr>
<td><em>Accipter novaehollandiae</em></td>
</tr>
<tr>
<td>Peregrine falcon</td>
</tr>
</tbody>
</table>

The ultimate predators were humans. By hunting and imposing fire regimes,\textsuperscript{20} Aboriginal people greatly influenced fauna populations. They preyed on adult and pup dingoes which were both a delicacy and raised pups for hunting.\textsuperscript{21} ‘Despite their close association with humans from puppyhood, dingoes almost always returned to their natural habitat once they reached sexual maturity, never to be seen again.’\textsuperscript{22} In southeast Australia Kooris traditionally hunted marsupial herbivores and wore brushtail possum skin cloaks. Early Europeans were predators after the end of Aboriginal hunting and elimination of the dingo led to massive herbivore increases, enabling koala and brushtail possum fur export industries.\textsuperscript{23} Before their protection, this increased hunting caused a range contraction in the koala but not the possum.

With humans as the top predator hunting thylacines, dingoes and devils\textsuperscript{24} these prey were by definition mesopredators\textsuperscript{25} in the Aboriginal novel ecosystem except in areas rarely visited such as deep wet forest where they were effectively top predators. In now remote areas where human hunting has ceased the dingo and devil have been promoted to top predator.

Long gone are the Pleistocene giant top carnivores *Thylacoleo, Megalania* and *Wonambi* along with many of their large prey herbivores such as *Diprotodon* and *Zygomaturus*. Most appear to have gone extinct 50,000 to 45,000 years ago soon after humans colonised Australia during a period with no exceptional climate change, and a human cause has been inferred\textsuperscript{26,27,28} although this is subject to debate\textsuperscript{29,30} Both directly by hunting and indirectly by fire the Aboriginal people may have wiped out almost all of the megafauna and many smaller species as well, causing more mammal extinctions (some 50 species weighing at least ten kilograms\textsuperscript{31}) than the Europeans (22 species in total\textsuperscript{32}). Since the arrival of the first humans, followed by the later arrival of the dingo and then Europeans with their domestic and invasive animals, southeast Australia has had a very different food web. Throughout this turbulent history predators are likely to have continued to control herbivores.
Figure 2. Humans, the ultimate predator, some with brushtail possum skin cloaks (koogras)

Figure 3. Dingo, the terror of kangaroos and wallabies

Figure 4. Powerful owl, roosting with remains of staple prey
Mesopredators

A mesopredator can be killed at any stage of its life cycle by a larger predator species. The larger native terrestrial mesopredators include:

<table>
<thead>
<tr>
<th>Species</th>
<th>Status (Victoria based on DSE)</th>
<th>Original major predators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot-tailed quoll <em>Dasyurus maculatus</em></td>
<td>endangered, rare in Tasmania</td>
<td>dingo, eagle, large owls</td>
</tr>
<tr>
<td>Eastern quoll <em>Dasyurus viverrinus</em></td>
<td>regionally extinct, secure in Tasmania</td>
<td>dingo, eagle, large owls</td>
</tr>
<tr>
<td>Western quoll <em>Dasyurus geoffroii</em></td>
<td>regionally extinct, vulnerable in WA</td>
<td>dingo, eagle</td>
</tr>
<tr>
<td>Short-beaked echidna <em>Tachyglossus aculeatus</em></td>
<td>secure, widespread</td>
<td>dingo, goanna, large raptors, human</td>
</tr>
<tr>
<td>Laughing kookaburra <em>Dacelo novaegineae</em></td>
<td>secure, widespread</td>
<td>large raptors, large owls</td>
</tr>
<tr>
<td>Lace monitor <em>Varanus varius</em></td>
<td>endangered, mainland only</td>
<td>dingo, eagle, human</td>
</tr>
<tr>
<td>Sand goanna <em>Varanus gouldii</em></td>
<td>secure, mainland only</td>
<td>dingo, eagle, human</td>
</tr>
<tr>
<td>Carpet/diamond python <em>Morelia spilota</em></td>
<td>endangered, mainland only</td>
<td>dingo, human</td>
</tr>
<tr>
<td>Tiger Snake <em>Notechis scutatus</em></td>
<td>secure, widespread</td>
<td>various birds, human</td>
</tr>
</tbody>
</table>

There are also many smaller mammal, bird, reptile and amphibian mesopredators.

Meet the mesopredators (some of the larger ones):

Figure 5. Lace monitor, venomous and deadly to possums
As part of a global pattern of predator loss in regions occupied by humans, most of the native terrestrial top predators and mammal mesopredators of southeast Australia are extinct or their populations are fragmented and reduced. The late arrival Europeans sent yet another large carnivore extinct (the thylacine), and are responsible for several smaller predator declines. Reasons vary with species and include persecution, poison baiting, habitat loss, fragmentation and alteration, disease, roadkill, and competition with and predation by novel predators.
Melbourne area

The fauna of the Melbourne area in 1853–57 was described by professional hunter and naturalist Horace William Wheelwright. His camp was never more than 40 miles from Melbourne and most of his time was spent in the upper regions of the Mornington Peninsula.

He wrote the following accounts of the larger predators:

Top predators

Dingo: ‘met with in all the thick forests, deeply-scrubbed gullies, in belts of timber bordering the large plains... throughout the whole country’.
Comment: an alien but now almost native species occurring in all habitats, feeding mainly on macropods and then sheep, dingoes were persecuted early by poison baiting and no longer occur in most of Victoria including the Melbourne area.

Wedge-tailed eagle: ‘by no means uncommon in our district at all seasons, often in pairs, both in the deep forests and on the plains... when gorged with carrion by no means difficult to approach’.
Comment: Revered as Bunjil by the Kulin people, pairs continue to reside in large home ranges in most rural and some peri-urban areas, a pair recolonised Mount Eliza in 2015.

Powerful owl: ‘by no means rare and seemed to remain in our forests throughout the year.’
Comment: preys on arboreal marsupials, possums are the staple diet especially common ringtail possum, range reduced and fragmented by loss of large hollow-bearing trees, now absent or transient in many areas but pairs are resident on the southern Peninsula.

Grey goshawk: ‘I only killed one specimen in our district, and this was by a water-hole; but I have heard they are common in many of the gullies where the native pheasant [superb lyrebird] abounds.’
Comment: specialises in hunting below the canopy for birds and possums.

Peregrine falcon: ‘common on our plains in autumn, but I do not fancy they bred in our district’.
Comment: has adapted to tall buildings and cliffs in disused quarries for nesting.

Mesopredators

Spot-tailed quoll: ‘rather a rare animal... sparingly dispersed over the thick bush... They must be very destructive to the small game in the bush’.
Comment: ground and arboreal (scansorial) predator, fast and agile in trees with feet adapted for climbing (serrated foot pads, opposable thumb on hind feet), midstorey dependent to avoid ground predators (dingoes) and find prey (mainly possums and birds), extremely rare in its contracted mainland range except for the remote southeast, extinct in the Melbourne area.

Eastern quoll: ‘one of the commonest of all the bush animals’.
Comment: ground predator and large consumer of native rats, extinct on the mainland.

Lace monitor: ‘frequents gullies and ranges where the timber is high, and the localities wild and unfrequented. It was very rare in our district; in fact, it is found only in the most solitary places.’
Comment: ground and arboreal (scansorial) predator, very rare then possibly due to persecution, varied diet includes possums and rats, common ringtail possum is the staple diet in East Gippsland and is easy and conspicuous prey in its drey during the day, functionally extinct on the Mornington Peninsula with occasional escapes or releases but no breeding population, still occurs in forested hills and ranges to the east.
Novel predators

Three novel mammal predators have been introduced by humans:

**Dingo/dog**

Introduced by Asian seafaring traders some 3500 years ago, the dingo *Canis lupus dingo*, sometimes *Canis dingo*, replaced the thylacine and devil as ground predator and scavenger on mainland Australia. It too could live as a mesopredator in predator-prey balance with Aboriginal people. Due to persecution by Europeans it is extinct over most of its former range in southeast Australia but is now the top ground predator in remote eastern areas.

![Figure 9. Dingo](image)

Arriving with Europeans, the dog *Canis lupus familiaris* is widespread but there is no evidence of persistent feral populations. Apart from recent escapes and releases, ‘wild dogs’ have at least some dingo ancestry. While little hybridisation with dingoes is physically evident, DNA analysis indicates that most ‘wild dogs’ in southeast Australia are hybrids while some remote animals are pure dingo. This suggests there is strong selection for dingo characteristics which include an annual rather than year-round breeding cycle. In order to protect livestock, dingoes / wild dogs have been eliminated or are kept at low levels in modified areas by control efforts while roaming domestic dogs can be significant predators.

Apart from the now almost native but restricted dingo, two more recent novel mesopredators are widespread and common in southeast Australia:

- Red fox *Vulpes vulpes*
- Cat *Felis catus*

Both have evolved to live with or near humans but can live without humans. They are partial replacement mesopredators in the extensive novel ecosystem where native predator pressure is low or nil. Somewhat similar to the quolls, which were once ‘native cats’, each is larger than its respective quoll. There is overlap in diet and behavior but no full species equivalence. Neither is very arboreal so they don’t replace the spot-tailed quoll, an adept climber. They changed the predator regime to being mesopredator-based and ground-based.
Red fox

The red fox *Vulpes vulpes* is a ‘highly adaptable, unspecialised and versatile’ ground predator of native and introduced fauna that is common throughout southeast mainland Australia. The red fox *Vulpes vulpes* is a ‘highly adaptable, unspecialised and versatile’ ground predator of native and introduced fauna that is common throughout southeast mainland Australia. "

Foxes are wily opportunistic omnivorous predators and scavengers. In a study of foxes in the Dandenong Creek valley in Melbourne over a two year period up to 38% of fox scats contained mammal hair. Of these, 54% contained the hair of introduced pest mammals (black rat, house mouse, European rabbit), 44% contained hair of common native mammal herbivores (common ringtail possum, common brushtail possum), and 0.4% contained hair of sugar glider – two scats. Mammals contributed 22% and birds 5% to the fox diet.

Figure 10. Red fox

A long-term study found the diet of foxes in southeast Australia consists largely of insects, rabbits, house mice, sheep lambs and carrion, rats, reptiles and plant material. The diet of foxes and dingoes / wild dogs overlap but the diet is wider for foxes with more insects and medium to small mammals consumed. Listed native species of conservation significance occurred at low frequencies (<0.2%) in fox scats except for broad-toothed rat (1.5%). Foxes were also eaten and presumably preyed on by dingoes / wild dogs. Scat analysis does not distinguish predation from scavenging which can be significant for predators. Other evidence indicates that foxes become the hunted. Foxes can limit kangaroo populations by preying on emergent pouch young. Like dingoes, they also prey on livestock.

The fox and dingo but apparently not the feral cat exhibit surplus killing of prey which does not endear them, but quolls also show this behaviour which led to their persecution.

Foxes are susceptible to the same diseases as dogs which are transmissible between the species. Mange and distemper are important causes of mortality in wild fox populations. The fox is suspected of being a vector of the mange mite to wombats through burrow sharing but this has not been confirmed. Mange, which occurred in Australia before the fox and also occurs in Tasmania where there are no foxes, is also likely to be transferred by dogs and dingoes. A potential problem with the fox in Australia is that elsewhere foxes carry rabies.

The fox has partly replaced a suite of original predators: Aboriginal people, the dingo and the two quolls, and is fully integrated into the novel ecosystem. While a threat to some fauna the fox imposes top-down control of native and novel herbivores which is a necessary ecosystem function. By preying on possums the fox protects tree canopies, by preying on rabbits it assists native vegetation generally, and by preying on digging rats it assists geophyte plants.
Cat

The cat *Felis catus* is a widespread opportunistic predator of native and introduced fauna in southeast Australia. There is a feral population of variable size depending largely on the abundance of rabbits, and roaming domestic cats are locally common.\(^{51}\)

![Figure 11. Cat](image)

Feral cats are not usually a significant predator of birds:\(^{52}\)

The widespread belief that feral Cats are a significant predator of birds appears to be misplaced. Although cat predation can be significant on small, isolated populations of birds, such as seabird colonies, and on species with low powers of dispersal, birds usually comprise less than 15% of the diet… In cleared or semi-cleared environments, young European Rabbits and House Mouse are the major prey items. In extensive tracts of bushland, where rabbits and mice are uncommon or absent, a wide range of native small mammals is eaten, including native rodents, Common Ringtail Possum, Feathertail Glider, Sugar Glider, insectivorous bats… and species of antechinus. The relative frequencies of various species in stomach contents or scats suggest that Cats opportunistically prey upon the most abundant or readily captured species.

Similarly, in a study of the diet of domestic cats in homes bordering nature reserves in Canberra most prey items were introduced pest mammals (64%), especially mice and rats. Native birds formed 14% of prey items and (native) reptiles 7%.\(^{53}\) Cats are likely to be major predators of reptiles in Victoria.\(^{54}\) Cats in turn are eaten by foxes and dingoes / wild dogs.\(^{55}\)

Cats spread the parasitic disease toxoplasmosis caused by the protozoan parasite *Toxoplasma gondii* to grazing animals, including many native species.\(^{56}\) Cats are the definitive host and marsupials can be intermediate hosts. Toxoplasmosis is a significant cause of morbidity and mortality in wild marsupials but its impact at a population level is not well known.\(^{57}\)

Being smaller than foxes, cats don’t play a major role in limiting the larger native herbivores, but with foxes they limit mouse, rat, rabbit and ringtail possum populations.

**Legal status of novel predators**

The negative effects of introduced predators have long been recognised in Victoria. Predation by cats and foxes are listed potentially threatening processes under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act). The Victorian *Catchment and Land Protection Act 1994* (CaLP Act) recognises foxes as established ‘pest animals’ and requires private landowners and public land managers to prevent the spread of, and as far as possible, eradicate established pest animals. Feral cats are recognised as ‘pest animals’ by the Victorian government and control is advocated in high value areas such as national parks.

In Victoria, wild dogs are pest animals and can be legally controlled. Dingoes are protected wildlife and it is an offence under the *Wildlife Act 1975* to kill a dingo without authorisation. To allow for the control of wild dogs and dingoes where they threaten livestock on private land, the dingo is declared ‘unprotected wildlife’ in certain areas and along the boundaries of public land in some areas, with the aim of conserving the dingo on most public land.\(^{58}\)
Native herbivore imbalance

Under low predator pressure several native (and novel) mammal herbivores increase to become overabundant in southeast Australia as indicated by loss of site biodiversity:

Table 3. Native herbivore imbalances

<table>
<thead>
<tr>
<th>Species</th>
<th>Original major predators</th>
<th>Current major predators (Mornington Peninsula)</th>
<th>Ecological imbalance with low predator pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red kangaroo Osphranter rufus</td>
<td>Dingo, eagle, human</td>
<td>n/a</td>
<td>Loss of plant diversity in Mallee national parks and reserves</td>
</tr>
<tr>
<td>Eastern grey kangaroo Macropus giganteus</td>
<td>Thylacine, dingo, eagle, human</td>
<td>Red fox, dog</td>
<td>Overgrazing inside predator enclosures and by very high unrestrained populations in many locations in Victoria, especially on urban fringes</td>
</tr>
<tr>
<td>Western grey kangaroo Macropus fuliginosus</td>
<td>Dingo, eagle, human</td>
<td>n/a</td>
<td>Loss of plant diversity in Mallee national parks and reserves</td>
</tr>
<tr>
<td>Black wallaby Wallabia bicolor</td>
<td>Dingo, human</td>
<td>Red fox, dog</td>
<td>Loss of plant diversity in Royal Botanic Gardens Cranbourne and Booderee National Park, Jervis Bay</td>
</tr>
<tr>
<td>Koala Phascolarctos cinereus</td>
<td>Dingo, human</td>
<td>Dog</td>
<td>Tree canopy loss in several locations in Victoria including Otway Ranges</td>
</tr>
<tr>
<td>Common brushtail possum Trichosurus vulpecula (primarily herbivorous, strictly an omnivore)</td>
<td>Thylacine, dingo, spot-tailed quoll, lace monitor, human</td>
<td>Red fox, cat</td>
<td>Tree loss in River Red Gum woodland on fringes of Melbourne and along Murray River</td>
</tr>
<tr>
<td>Common ringtail possum Pseudocheirus peregrinus</td>
<td>Spot-tailed quoll, lace monitor, powerful owl, dingo, grey goshawk, tiger snake, human</td>
<td>Red fox, cat, powerful owl (southern Peninsula)</td>
<td>Tree canopy loss in southern Melbourne and on northern Mornington Peninsula</td>
</tr>
<tr>
<td>Swamp rat Rattus lutreolus</td>
<td>Eastern quoll, ?human</td>
<td>Red fox, cat</td>
<td>Loss of orchid populations on Mornington Peninsula</td>
</tr>
</tbody>
</table>

These species have become overabundant as free range populations outside predator enclosures wherever their predator pressure is sufficiently reduced. They are 7 of 18 native mammal herbivores in the region and they include most of the larger species (Appendix 1).

Some of the others could be included. Common wombats create localised ‘marsupial lawns’ in forest which generally add to habitat and species diversity, however their overgrazing of grassland at Wilsons Promontory along with hog deer is a problem. Wombats are usually limited by dingoes. It is noted that 4 of the 18 native mammal herbivores are threatened species. There are also 8 novel mammal herbivores, all with the potential for overpopulation.

None of these herbivores appear to have a population self-regulating mechanism – they continue to breed as per their normal cycle despite dwindling food supply. At sustainable densities under predator control herbivores do not destroy their food resource, but they maintain reduced vegetation cover and so can be secondary keystone species. For example black wallabies limit shrub cover, preventing shrubs from shading out the ground layer flora and fauna. Kangaroos reduce grass cover which also facilitates ground layer diversity. Swamp rats control sedges with the potential for overdominance.

Novel herbivores can also be secondary keystone species. Pulse sheep grazing keeps native grassland relatively healthy. Rabbits at Yarra Bend are food for raptors and grazers of exotic veldt grass. Rabbit control led to disappearance of the raptors and increased weeds.59

Herbivores are vital for ecosystem diversity and stability when in balance but without their predators they can increase to destroy their food resource. This results in a decline or crash in their population and for other species left with insufficient resources such as trees. They starve themselves out and wreck the habitat for other species.
**Predator exclosures**

Predator exclosures contribute to threatened fauna conservation by excluding large ground predators and are a great way to see rare fauna. An interesting and consistent effect of predator exclusion is herbivore release leading to herbivore imbalance. Every large exclosure in the region has undergone herbivore imbalance, be it from rabbits to wallabies or kangaroos.

The flora and fauna that are reduced or effectively wiped out within these remarkable ecological dysfunction zones vary with the overabundant herbivore, from the ground layer (rabbits, kangaroos), through the shrub layer (wallabies) to the canopy layer (possums). Multiple herbivore imbalances have occurred. Unless bottom-up controlled by physical factors, herbivore populations inevitably grow to exhaust their food resource and then starve.

Numerous major herbivore imbalances have occurred inside predator exclosures. It has been necessary to take corrective action in each exclosure.

<table>
<thead>
<tr>
<th>Exclosure</th>
<th>Herbivore</th>
<th>Excluded predator</th>
<th>Ecological damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mulligans Flat Woodland Sanctuary Gungahlin</td>
<td>European rabbit, Eastern grey kangaroo, Red-necked wallaby, Black wallaby</td>
<td>Dog, red fox, cat</td>
<td>Severely grazed ground layer</td>
</tr>
<tr>
<td>Grassy Woodland</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mount Rothwell Little River</td>
<td>European rabbit, Common brushtail possum, Southern bettong</td>
<td>Red fox, cat</td>
<td>Severely grazed ground layer, tree canopy damage</td>
</tr>
<tr>
<td>Hills Herb-rich Woodland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodlands Historic Park Greenvale</td>
<td>Eastern grey kangaroo</td>
<td>Dog, red fox</td>
<td>Severely grazed ground layer</td>
</tr>
<tr>
<td>Hills Herb-rich Woodland</td>
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<td></td>
</tr>
<tr>
<td>Royal Botanic Gardens Cranbourne</td>
<td>Black wallaby</td>
<td>Red fox, dog</td>
<td>Severely grazed shrubs and forbs</td>
</tr>
<tr>
<td>Healthy Woodland, Grassy Woodland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Briars Mornington</td>
<td>European rabbit, Common brushtail possum, Common brushtail possum, Swamp rat</td>
<td>Red fox, cat</td>
<td>Overgrazed ground layer, tree canopy damage, orchid loss</td>
</tr>
<tr>
<td>95 ha, Grassy Woodland</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>La Trobe Wildlife Sanctuary Bundoora</td>
<td>Eastern grey kangaroo, Common brushtail possum</td>
<td>Dog, red fox</td>
<td>Severely grazed ground layer, tree canopy damage</td>
</tr>
<tr>
<td>30 ha, Plains Grassy Woodland</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

With protected captive kangaroos, body condition declines with ‘intensification of intraspecific competition as density increases’ and animal health and welfare issues arise.\(^{60}\)
The Woodlands Historic Park kangaroo overpopulation is described in the research literature\textsuperscript{61,62} but why isn’t more of this written up? There are several reasons including:

- None of the exclosures have appropriate baseline ecological data collected before change was made on the ground on which to base future comparison except for flora data and some fauna data for Mulligans Flat.\textsuperscript{63,64,65} The relevant variables to measure were (a) predator, omnivore and herbivore density and biomass by species, and (b) plant cover and biomass by species and vegetation layer. This lack of baseline data stymies research.
- The exclosure projects were mostly conceived as being ‘a good thing’ that didn’t need more science or at least didn’t need before and after site monitoring. There was no awareness that the site ecosystem was predator dependent and that ecological imbalances might result from removing all ground predators. Most attention was given to the small number of protected or reintroduced mammal species. Mulligans Flat has several ongoing experiments although none involve reintroducing predators such as dingoes or goannas.
- Exclosure managers have been generally surprised by the ecological dysfunctions that have occurred and do not want to publicise them as the projects are meant to be ecological restoration. In each exclosure there have been attempts to control the herbivore irruptions by various means including by direct culling but many of the imbalances remain. There has also been a tendency to view each exclosure’s imbalance problems as being unique when there is a consistent pattern across all exclosures in the region.

Is overpopulation simply due to an inability of the herbivores to disperse? The ‘fence effect’ has been reported in small mammals (voles) where enclosed populations reached high densities.\textsuperscript{66} However, the reported effect was likely due to small predators (shrews) being eliminated by the fencing rather than by emigration being prevented.\textsuperscript{67} In any case, dispersing animals are subject to the normal background predator pressure. If the novel predators were to suddenly go extinct, much of the region would presumably look like the exclosures.

All herbivores and omnivores have the potential to overpopulate and starve inside predator exclosures, unless they are habitat limited by lack of physical shelter in which case they cannot eat all of the available food and the surplus young die from exposure, injury or stress instead of starvation or predators. For example southern bettong and red-necked wallaby become overabundant inside exclosures but not in the wild where they are predator limited. We haven’t seen overabundance in more species because not all of them are inside exclosures.

There are winners and losers in modified systems and in this case unnatural predator-free systems. Some flora and fauna benefit, such as unpalatable plants and their associated insects, but they are in the minority and are often introduced species. Most species are losers.

The negative impacts of predator exclosures indicate a net positive influence of the novel predators on present-day modified ecosystems and landscapes. They have had most of their impact on sensitive native fauna since their introduction, and it is now the majority preadapted or evolving species that coexist with them without being conservation dependent. When they were established the exclosure sites had already lost their sensitive fauna, and their herbivore levels were relatively low under novel predator pressure with systems in equilibrium. The contributions from the dog, fox and cat in providing that essential background predator pressure depended on the site. Dingoes were already extinct at all sites.

Experience with the predator exclosures reveals that novel predators normally stabilise the widespread novel bushland ecosystems in human occupied parts of the region by exerting system predator pressure as native predators are frequently missing. Together with any remaining native predators they are essential in order to keep bushland ecosystems relatively healthy and balanced. The continual pressure they place on herbivores is pervasive but not always noticed except when it is removed and systems are damaged by excess herbivory.
**Case studies – species**

The following case studies explore native mammal herbivore imbalance, in order of animal size, with a focus on ringtail possum induced tree decline on the Mornington Peninsula.

**Kangaroos**

Kangaroos were once controlled by predatory humans, thylacines and dingoes as well as by drought. Hunting is now reduced or non-existent in southeast Australia. Consequently kangaroo populations are high and further increased by the clearing or fragmentation of forest and the provision of water in farm dams and other artificial stock water points.

‘The negative impacts of high kangaroo density include threats to humans, depression of threatened species, decline in body condition of kangaroos, and altered grazing equilibria.’

‘In overpopulated areas, kangaroos can cause damage to farmland, property and habitat, pose a risk to human safety, and can suffer starvation from overgrazing. Kangaroo control is important in these areas to protect the environment, people and the welfare of kangaroos.’

Commercial harvesting of kangaroos is permitted by the Australian government in most states. ‘The commercial kangaroo harvest industry in Australia is one of the world’s best practice wild harvest operations, with management goals based firmly on principles of sustainability… The scientific community and state wildlife management agencies consider that annual harvest levels in the order of 15 per cent of the populations for grey kangaroos and wallaroos, and 20 per cent for red kangaroos, are sustainable… The Australian government controls the export of kangaroo products through the approval of kangaroo management programs and the granting of export permits.’

Victoria is conducting a kangaroo pet food trial on private land to manage kangaroo numbers and reduce waste but is not otherwise engaged in the commercial harvesting of kangaroos.

It has been argued that kangaroo production could replace a portion of sheep production in the rangelands of Australia, with significant environmental benefits – ‘sheep replacement therapy’ would enable better management of total grazing pressure on rangelands. Furthermore, methane from cattle and sheep constitutes 11% of Australia’s total greenhouse gas emission while kangaroos produce negligible amounts of methane.
**Red kangaroo**

The red kangaroo *Osphranter rufus* is a large gregarious mammal found across arid and semiarid Australia extending into northwest Victoria (the Victorian Mallee).

In Victoria numbers have increased since the mid-90s when the population was described as ‘relatively small (about 6000) and probably experiences periodic fluctuations’. In addition to low predator pressure, it is likely the removal of sheep, which compete for food with kangaroos, from the Murray-Sunset National Park declared in 1991 and from other conservation land as well as intensive rabbit control led to the increase. Reds also benefited when western grey culling began as there was less competition for food.

Hattah-Kulkyne National Park has experienced a classic herbivore replacement process in which the rabbit, western grey and then red kangaroo partly replaced each other due to reduced competition from the previous herbivore after management intervention. Following rabbit control in the early 1980s, western greys increased until their culling began, which then allowedreds to increase. The two kangaroo species underwent ecological release in turn.

Kangaroo population control is currently part of a restoration program across 22,600 hectares of threatened woodland in Hattah-Kulkyne National Park and 124,700 hectares in Murray-Sunset National Park. Permits to cull 10,680 red kangaroos were issued in 2016 but a lower number was culled. Permits to cull 5,105 were issued in 2017.
**Eastern grey kangaroo**

The eastern grey kangaroo *Macropus giganteus* is a large gregarious mammal found through much of southeast Australia. ‘Feeding activity is concentrated in areas where grasses are most abundant. Other monocotyledons and dicotyledonous forbs are eaten in varying amounts depending on the composition of vegetation and seasonal conditions.’

![Eastern grey kangaroo](image)

**Figure 15. Eastern grey kangaroos**

Eastern grey kangaroo populations were naturally substantial and appeared to increase after the end of Aboriginal and dingo hunting and the clearing of forests. ‘Substantial numbers were noted by early explorers and travellers in Victoria. Subsequently during the first few decades of pastoral expansion (1840 to 1880) there was an apparent increase in the abundance of this species.’ Populations have remained large where they have the necessary combination of low predation, grassy areas and water.

Foxes limit eastern grey populations by preying on emergent pouch young but the predator-prey balance is in favour of the roos so populations remain large in many areas. Populations reach even higher and extreme levels inside nature reserves without any predators.

Overgrazing inside predator exclosures and by very high unrestrained populations is now a major conservation management problem in many locations in southeast Australia, especially on urban fringes. Brett Howland and Don Driscoll report:

- Eastern grey kangaroos reach very high densities in southeast Australia due to the absence of predators and ready access to permanent water in farm dams.
- At high densities, kangaroos reduce the abundance and diversity of plants and reptiles, and degrade habitat for birds and mammals.
- The vulnerable striped legless lizard declines dramatically with high kangaroo densities.
- The literature recommends that grazing pressure be reduced where kangaroos are overabundant to prevent biodiversity loss.

Culling of eastern grey kangaroos for conservation purposes occurs in several locations in the region such as around Canberra and can be controversial due to objections from animal rights activists. At Woodlands Historic Park on Melbourne’s northern fringe it became necessary to cull kangaroos inside the predator exclosure for eastern barred bandicoots as without shelter the bandicoots were highly vulnerable to predators including raptors.

Permits to cull 3,750 eastern grey kangaroos on seven areas of public land in Victoria including 3,000 in the Puckapunyal Military Area were issued in 2016. Permits to cull 130 were issued in 2017.
Western grey kangaroo

The western grey kangaroo *Macropus fuliginosus* is a large gregarious mammal found through western Victoria and adjacent areas extending to southern Western Australia.

![Western grey kangaroos](image)

As with red kangaroos, in addition to low predator pressure, western grey kangaroos have increased in the Mallee national parks likely due to the removal of sheep and intensive rabbit control. When the parks were created in the 1990s some 90% of the stock water points were closed, so increased water availability cannot explain the long-term increase.

Large uncontrolled populations of western grey kangaroos negatively impact on biodiversity by contributing to overgrazing and erosion. *‘High densities in at least one reserve, Hattah-Kulkyne National Park, are in conflict with management goals to rehabilitate vegetation communities degraded by past overgrazing, and there is an active management program to control kangaroo numbers.‘* 89,90 Western greys also inhibit the recruitment of canopy trees in woodlands of cypress-pine and sheoak, and cause soil erosion on dunes.91

A culling trial found an increase in native biomass and in several rare or threatened plant species where kangaroos were culled compared with unculled areas.92

Culling of western grey kangaroos was first undertaken in Hattah-Kulkyne National Park in 1984 and has continued from 1990 onwards. Permits to cull 10,455 western greys in three national parks in Victoria were issued in 2016 but a lower number was culled. There were objections from animal rights activists.93 Permits to cull 1,916 were issued in 2017.94

As a result of the ongoing grazing management program, natural regeneration of native woody plants is now occurring in the Mallee national parks although it is patchy. Returning dingoes to the parks would lessen the need to cull for biodiversity. Land managers are aware of the conundrum: dingoes would be good for conservation inside the parks but potentially bad for sheep production on adjacent cleared farmland should they cross the park borders.
Black wallaby

The black wallaby *Wallabia bicolor* is a large marsupial browser of shrubs and other plants. Along with fire, it is a major regulator of shrub cover on mainland southeast Australia. Wherever wallabies occur their characteristic pruning of regenerating shrubs can be seen below the wallaby browse line (about one metre) and is good for ground layer diversity by limiting the density of the shady midstorey. But when overabundant, wallabies deplete low shrubs and prevent the recruitment of all woody species including trees.

Wallaby overpopulation is occurring within the 250 ha predator exclosure at Royal Botanic Gardens Cranbourne southeast of Melbourne. Novel predators are kept out by a predator fence installed in 2003 to protect southern brown bandicoots. Bandicoots are now unnaturally abundant but were common before the fence even with foxes due to dense vegetation cover. Without foxes the wallaby population has exploded resulting in loss of plant diversity.

![Figure 17. Predator fence on perimeter of RBG Cranbourne](image)

Another telling example is documented for Booderee National Park, Jervis Bay in southern New South Wales. Unpalatable bracken is taking over because intensive fox control has allowed a 10-fold increase in black wallabies which are eating out the understorey. The forest habitat may be transformed into ‘a low diversity bracken fern parkland… through a trophic cascade, similar to that caused by overabundant deer in the northern hemisphere’.

The Cranbourne and Booderee experience indicates the black wallaby is and always has been controlled by predators rather than food supply in southeast Australia. Predator pressure operates on this herbivore everywhere, previously largely from dingoes and now foxes. It also reveals the role of the wallaby in controlling shrub cover and thus ground layer diversity.

The wallaby browsing effect was first demonstrated in exclosure plot experiments in Lilly Pilly Gully at Wilsons Promontory by David Ashton in the 1970s: exclosures became shrubby. Ultimately predators are controlling shrub cover and regulating biodiversity.
The koala is a large arboreal marsupial which is ‘probably the most recognised and well-liked of Australia’s mammals’. While listed as vulnerable in the northern part of their range, koalas can be overabundant in the south.

Overabundant koala populations impact on their habitat by overbrowsing their food tree species in several coastal areas and on some islands of Victoria including the Portland area, Mount Eccles, Framlingham Forest, the Otway Ranges, French Island and Snake Island.

Coast manna gum *Eucalyptus viminalis* subsp. *pryoriana* is particularly at risk, but koalas also impact on manna gum *E. viminalis* subsp. *viminalis*, swamp gum *E. ovata*, blue gum *E. globulus* and river red gum *E. camaldulensis*. Koalas in sustainable numbers may contribute to control of tree cover but kill whole tree canopies when overabundant.

The koala overpopulation problem has been much studied. The Victorian government has used translocation as a management technique as well as in situ hormonal contraception or surgical sterilisation to manage overabundant populations. Koalas were released at Cape Otway in 1981 where they increased without sufficient predation to overreach the habitat carrying capacity in about 20 years which is usual for koala introductions. With koala density five times the carrying capacity, manna gum canopies destroyed and large numbers of koalas starving, almost 800 starving koalas were put down in the two years to 2015. The koalas were captured and sedated before being euthanased. Another 400 koalas were moved within Great Otway National Park to west of Aireys Inlet where habitat is less optimal as their food eucalypts are not the only eucalypts in the canopy. Any other healthy individuals were released so the population problem remains.

Several factors control koala populations, notably predators (now mainly dingoes/dogs), bushfire, food quality and quantity, vehicles and disease. There is evidence that predation by Aboriginal people and dingoes kept koala numbers very low prior to Europeans.

Dingoes were once prevalent in the Otways. ‘In some of the mountainous parts of Victoria, but especially in the Otway Ranges, the dingoes were so very numerous and fierce, and hunted in such large packs, that the natives were afraid to venture among them, and often had to take refuge in trees’ and ‘in the Cape Otway forest… they are large and fierce’. Koalas were presumably favourite prey for dingoes at Cape Otway. These accounts also suggest that humans were barely able to control dingoes through their predation on them.

Koalas are difficult and expensive to manage as it is hard to create the necessary fire or predator regime. Lighting fires or relying on roadkill to cull koalas is not ethical. The message: don’t reintroduce fertile koalas into optimal habitat where all the canopy trees are primary food species unless the required predators are there, which is unlikely. Otherwise culling is necessary before the koalas kill their trees and damage the ecosystem.
**Possums**

The common brushtail possum and common ringtail possum are widespread nocturnal marsupials that feed mainly on the foliage of many eucalypt species. While mainly herbivorous, the brushtail may also prey on insects and occasionally on bird eggs. These form a small part of its diet, so the brushtail is grouped with herbivores here.

Tree loss from mammal browsing was not reported from the vegetation of Victoria in its ‘original and natural’ condition and appears to be post-European contact. As early as the 1850s Wheelwright noted an irruption of brushtail possums 30 km from Melbourne from where their key predators including the Aboriginal people were already missing:

> The most I ever shot in one night was at a place called the ‘Banging Water-holes’, near Dandenong: the trees were old and bare; the night still and clear. I killed ninety-three. This was an unusual occurrence; but a man may always with little trouble kill a dozen on any night in the forests where the possums are at all thick.

By the 1870s Aboriginal people at Framlingham in western Victoria were ‘accusing’ brushtail possums of killing trees. ‘The possums were no longer hunted and their numbers had risen… Possums also benefited when dingoes were culled.’

Possums have caused tree canopy loss in many parts of suburban and rural Victoria. Canopy loss has negative cascade effects on both flora and fauna resulting in local extinctions. Curiously, coast manna gum *Eucalyptus viminalis* subsp. *pryoriana*, a locally dominant tree in heathy woodland, is relished by koalas but avoided by possums.

**Figure 19. Manna gum woodland killed by ringtail possums, Tangenong Creek, Frankston South**

Tree loss from folivores has been called dieback, but trees affected by folivores don’t die back, they’re eaten back. Dieback is associated with climatic extremes and tree decline is associated with human management in one interpretation. Tree loss from folivores is accordingly tree decline as it is due to human influence through the elimination of predators.

The questions that land managers throughout the wide geographic range of these possums need to answer are ‘what steps will most efficiently and effectively maintain tree canopy health?’ and ‘what is controlling tree canopy folivore numbers?’ Basic ecology suggests that if it is not predators then it will be other biotic factors such as competition, starvation or disease, or physical factors such as drought, heat, fire and availability of shelter. If control is by starvation there are dire consequences for trees and the species that depend on them.

**Legal status of possums**

Possums are protected under the Victorian *Wildlife Act 1975*. Since 2003 the government has permitted the trapping of common brushtail possums in buildings for the purpose of release on the same property up to a maximum of 50 metres from the capture site after sunset on the day of capture or, if that is not reasonably possible, taking them to a registered vet for euthanasia within 24 hours of capture. Relocation of possums is prohibited. Trapping allows access to a building to be sealed off but the homeless possum may then die from stress or predators. Common ringtail possums are fully protected and may not be trapped.
**Common brushtail possum**

River red gums *Eucalyptus camaldulensis* with open grassy understoreys can be killed by common brushtail possums (CBPs) that den in the natural cavities of larger trees.\(^{121,122}\) This form of tree decline is *brushtail possum associated decline* (BPAD).

Large old red gums are most susceptible as they shelter brushtails in their hollows. Each evening, brushtails check their home tree before venturing down to brave ground predators in order to browse on the ground and reach other food trees.

Woodlands of mature trees are most at risk as every tree potentially has possums. In woodland with scattered mature trees (with hollows) surrounded by immature regrowth, browsing pressure is lower and more distributed but home trees can still be killed. An isolated tree cannot sustain a brushtail, and brushtails are reluctant to cross large distances with foxes around, so isolated trees remain healthy, unlike in other forms of tree decline.

Unlike ringtails, a midstorey vegetation layer is not needed by the larger brushtails which are more active on the ground – they are scansorial. As well as eating the leaves of eucalypt trees, brushtails feed on ground layer vegetation, while ringtails cross ground to reach trees. Both are caught on the ground by foxes throughout their wide geographic range.

Brushtails change their behavior to reduce the risk of being caught. If foxes are present or if fox scent is placed on the ground, they spend less time on the ground, travel shorter distances, reduce time spent active, avoid open areas, and distinguish old from new scent.\(^{123}\) They prefer dense grassy ground layers resulting from low biomass control, and on these sites browsing pressure is more concentrated and tree decline is more evident.

Brushtail possums cause red gum decline in several areas of Victoria including the Wimmera and Riverina floodplains. The following November 2006 account is from Michael Eris O’Brien regarding Pine Grove, 34 km southwest of Echuca in the Riverina:\(^{124}\)

> I own a property on the Murray River floodplains, downstream of Echuca. My property has river red gum wetlands that have quite naturally not received any flooding since 1995.

> For the last 15 years my red gum wetland and many other red gum wetlands in the region have suffered massive decline in tree health and in some instances all of the trees have been killed. It is changing the look of the landscape and is quite obviously a regional catastrophe.

> But what is the cause? Ask any of the experts and they insist it is ‘drought’, but in my district the average rain for the past 15 years has only been slightly below the long term average and in reality the red gums have probably had as much flooding as they ever did in dry periods.

> The actual cause of the tree death is something much more cute and cuddly, common brushtail possums. Brushtail possums are abundant in these hollow red gums. At times I have spotted up to 15 mature possums in one tree. Each summer the trees grow a few leaves and then for the remainder of the year the possums strip them clean. The trees can only take about three years of this kind of constant bombardment before they die. From the 200 large trees within my wetland at least 75% have died in the last 10 years, and the remainder are in poor health.

> Prior to European settlement in the area, the local Aboriginals heavily utilised brushtail possums for food, clothing etcetera. So much so that one of the early pastoralists in the area referred to them as the ‘possum-eaters’.

> As an experiment I possum guarded a number of random trees last November.

> The following photograph I took this morning of one of the possum-guarded trees. The trees in the photograph were all in similar health at the time of guarding last November.

> Possum attack is a widespread problem in the Murray floodplains now that possums are unable to be utilised and managed, and probably explains a lot of the premature death of red gums that people are witnessing in this natural dry period.
What caused the possum increase is not clear. It had to be recent otherwise the trees would not have reached maturity in the first place. Was it nitrogen increase making the foliage more nutritious, a drop in predator pressure or some other factor? The swamp had received no fertiliser so nitrogen increase is unlikely. However fox shooting was being undertaken meticulously on the property and adjoining properties at the time. Furthermore, since then fox shooting has ceased and the surviving red gums have recovered.

Most fox mortality is due to dingoes where they occur, human intervention, drought or disease. The Pine Grove tree decline occurred during the prolonged Millennium Drought which included two periods of severe rainfall deficiency at Echuca in the two years prior to the banding (January–May 2004, March–May 2005), with both periods having close to the lowest rainfall on record. Drought may have impacted on foxes in addition to control.

Could drought change or stress the physiology of trees, increasing their leaf sugar content, encouraging browsing by possums at least until they kill the trees? Not significantly, BPAD is independent of rainfall, occurring in dry and wet years. For example it was severe at Pine Grove in 2005 during drought and at Craigieburn in 2016, a year of above average rainfall. Also, banded trees recover with healthy crowns and show little or no sign of stress.

Do CBPs maintain territories that are large enough to sustain the trees through aggression, with excess animals banished to die on the ground from stress, hunger or predators? Or are there limited tree cavities limiting possum numbers in a form of bottom-up control? Not in mature stands, as Michael O’Brien reported up to 15 mature possums in one tree.

CBPs produce one young per year in red gum forest near Echuca. Female CBPs may become pregnant before the end of their first year, so possum numbers without predators for two years may be twice (2.0) higher under exponential growth assuming equal sex ratios and long life expectancy (typically 12 years in captivity). This doubles the browsing pressure. At three years a population may be 2.9 times higher and at five years may be 5.8 times higher than its initial size. Clearly stable CBP populations in mature trees are being limited otherwise they would soon grow and destroy the trees. Resident predators normally control brushtails with tree canopies in moderate to good health under sustainable browsing pressure.
Predation rather than food supply appears to control this herbivore, otherwise the trees would be dead. Fire and roadkill are not sufficient. Predators effectively halve the average life span of adult CBPs, from 12 years down to 6–7 years, protecting woodlands in the process.

In many widespread remnants of river red gum woodland the major native predators of this major native folivore are rare or missing (Kooris, dingoes, goannas, quolls, pythons). As native predators become rare it is increasingly down to the fox to prevent brushtail possum irruption. In many situations it is down to foxes entirely. Foxes on their own can control possums down to the population level where the trees are browsed sustainably but the balance is precarious. Fox control by humans when effective upsets this balance as shown by defoliated red gums inside predator exclosures, indicating that the fox and brushtail are in predator-prey balance over extensive areas where foxes now mean trees.

At Pine Grove foxes are currently not hunted and have proved to be a minor predator of lambs compared to Australian ravens. Foxes have taken about 20 lambs in the last 20 years whereas ravens took some 70 lambs last year alone. And the red gum swamp is healthy again.

Recovery of red gums with installed possum bands has occurred at many locations in Victoria including Pine Grove, Donnybrook, Bundoora, Bulleen, Templestowe and Highett.

![Common brushtail possum tree recovery](image)

**From:** Michael Tregonning [mailto:Michael.Tregonning@manningham.vic.gov.au]
**Sent:** Monday, 2 November 2015 7:59 AM
**To:** 'Jeff Yugovic'
**Subject:** RE: Red gum on Fitzsimmons Lane

Hi Jeff,

I was happy to see the tree recover. All that was required was a piece of plastic!

Thanks

---

**Figure 21.** Possum band on recovering river red gum, Templestowe
In Mount Eliza on the Mornington Peninsula an overpopulation of common ringtail possum (CRP) is responsible for an unprecedented epidemic of eucalypt canopy loss. A major ecological malfunction has occurred. All six local eucalypts are susceptible except for manna gum *Eucalyptus viminalis* in which some individuals are not eaten. Repeated defoliation is required to kill a healthy tree. With up to 16 ringtail possums per hectare this is the highest recorded density of ringtail possum in natural eucalypt vegetation in Australia. This form of tree decline is *ringtail possum associated decline* (RPAD).

Research and observations as well as the recovery of trees with possum bands indicate an overpopulation of CRP is the main cause of decline. Other causes of mortality are minor: approximately 10% of tree loss is from tree removal and drought. Koalas are extinct. Borers structurally weaken but rarely if ever kill trees and defoliated dead trees can be free of borers. The ‘prognosis for the eucalypts remaining in the landscape is extremely poor’.

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**Figure 22.** Possum band or guard on swamp gum *Eucalyptus ovata*, Mount Eliza, clear plastic band on trunk protects tree crown from possums while unprotected side limb (on right) has died, before band the entire tree was largely defoliated, recovery took 1–2 years, photo taken during late recovery, the first possum banded tree in Mount Eliza, this tree has remained healthy for 25 years

**Figure 23.** Possum bands on swamp gum, Kunyung Road, Mount Eliza
Possum and koala damage can be recognised by hanging (pendant) branches with *uneaten* leaves. Possums don’t climb down descending vertical branches regardless of height over ground while ascending branches are variably defoliated. In comparison, insects, pathogens and disturbance affect all leaves equally on a limb or more usually throughout a tree, so mammal induced tree decline is *readily distinguished* from other forms of tree decline.

![Diagram of CRP damage](image)

**Diagnosis of CRP damage (RPAD)**

* new leaves eaten
* hanging (pendant) branches intact

Figure 24. Diagnosis of ringtail possum damage

A single hanging branch with its uneaten leaves cannot sustain a tree and will eventually die with the rest of the tree, making the cause of death clear when it occurs outside drought. Unless the tree is seen with live or dead uneaten leaves on hanging branches it will be impossible to tell what killed it six months after it dies when the dead leaves have fallen. By not seeing how trees decline and die in this particular way, trees killed by possums are sometimes later mistaken for trees killed by drought and other forms of mortality.

A possum-stressed tree may survive years of partial defoliation. Rare weeping trees with several hanging leafy branches can survive with a defoliated crown, and can be top pruned to form interesting specimen trees safe from possums. Typically a tree perseveres for a few years and then dies while still supporting a little eaten-back foliage. Trees in serious, critical and terminal condition are recognisable.

A consultant study for Mornington Peninsula Shire found brushtail possums at ‘low density in Mount Eliza for a peri-urban environment’. While this is so for the bushland reserves sampled, brushtails contribute significantly to browsing pressure on trees in gardens throughout Mount Eliza where they are near buildings with necessary shelter, there being few large eucalypt trees to house them. They eat fully grown leaves which thins the foliage evenly through trees, while ringtails are more damaging by being smaller and able to reach their preferred shoots and young leaves at the ends of branches, preventing leaves from attaining full size. As a leaf normally lives for one year and is then shed, trees unable to replace their fallen leaves are killed by repeated defoliation within a few years. This difference in leaf preference is reflected in their teeth, with brushtails having large blade-like premolars that curve outwards, an adaptation to tougher leaves.
The two possums thus have different browse patterns which can be seen in trees. Ringtail damage (RPAD) is readily distinguished from brushtail damage (BPAD). Scats on the ground also reveal which species is accessing particular trees. CRP is a causal factor in tree loss in Mount Eliza, while CBP is a contributing factor. In combination the two possum species are especially deadly to trees.

Many eucalypts native to the region are browsed by possums. Swamp gum *Eucalyptus ovata*, snow gum *E. pauciflora* and narrow-leaf peppermint *E. radiata* are highly palatable. All individuals can be killed, old and young, strong and weak. They appear to have no leaf chemical defence against CRP so other factors must limit possum density. Silver-leaf stringybark *E. cephalocarpa*, yellow gum *E. leucoxylon* and yellow box *E. melliodora* are also eaten. Possum stressed trees also appear to be more sensitive to drought and fire. On the other hand some species such as red box *E. polyanthemos* are resistant to possums.

The only eucalypt on the Mornington Peninsula with internal variation in palatability is manna gum *Eucalyptus viminalis*. Coast manna gum *E. viminalis* subsp. *pryoriana* is not eaten, presumably due to chemical defence in a habitat where shrubs abound and there is no avoiding possums otherwise. With the indeterminate subspecies, the ‘half-barked’ grassy woodland form of manna gum, possums have preferred trees while some trees are avoided. These resistant trees may have the ‘pryoriana gene’. Where possums are killing the susceptible manna gums in a population, seed should be collected from these resistant trees.

As the canopy eucalypts die, starving ringtails switch to less preferred species such as black sheoak *Allocasuarina littoralis*, drooping sheoak *Allocasuarina verticillata*, silver banksia *Banksia marginata*, sweet bursaria *Bursaria spinosa* and coast tea-tree *Leptospermum laevigatum*. This does not sustain them and only increases vegetation damage before they die. Ringtail overbrowsing also destroys coast tea-tree scrub on the southern Peninsula.

Several factors control populations of ringtail possum including availability of shelter, predators, fire, food quality and food availability. There were originally some 20 predators, mainly humans, dingoes, goannas, spot-tailed quolls, large raptors and large owls. Predators are now mainly foxes, cats, large raptors and large owls where they occur. Every few years, numbers plummet during intense heat waves. However, ringtail possums have high fecundity so populations can rapidly recover within a year and tree decline resumes.
Both possums reach higher densities in Melbourne urban bushland due to increased food resources in adjacent residential areas\textsuperscript{142} which may contribute to high browsing pressure in Mount Eliza. However, ringtail possum induced tree canopy loss occurs across the northern Mornington Peninsula from Mount Martha\textsuperscript{143} to Cranbourne and was locally severe in rural areas by the 1990s\textsuperscript{144} before it became severe everywhere including urban areas by 2010.

Within the severely affected area entire canopies are killed by ringtail possums, while outside this area only some trees are killed. RPAD is not restricted to the Mornington Peninsula, and occurs elsewhere in southern Victoria for example in Frankston, Braeside, Mordialloc, Wheelers Hill, Park Orchards and Ocean Grove. It occurs in a range of vegetation types with overgrown midstorey vegetation and is most prevalent in once open grassy woodlands.

Described locally as an ‘ecological emergency’, possum overbrowsing and occasional tree losses were occurring in Mount Eliza as early as the 1980s. Tree canopy decline was severe in Mount Martha by 1990\textsuperscript{145} and was later confirmed to be caused by ringtail possum.\textsuperscript{146,147} Tree loss then continued through the Millennium Drought (1996–2010 in Mornington) and first became generally severe with unprecedented complete canopy losses during the 2010–2012 La Niña events suggesting high rainfall may favour possums. However there were many previous La Niñas and successive years of high rainfall before the drought\textsuperscript{148} and none caused complete canopy loss. RPAD is independent of rainfall or drought stress. Other factors are operating. Importantly, the La Niñas accelerated the growth of both eucalypts and understorey in a long-term increase in understorey (midstorey) biomass.
Could a predator-prey imbalance between domestic cats and ringtail possums explain the late onset of decline in Mount Eliza relative to rural areas of the Peninsula? With the native predators long gone, domestic cats were at artificially high densities due to being fed and sheltered by their owners until 1997 when they largely disappeared from the landscape due to a local cat curfew. However, given the CRP overpopulation developed more than 10 years later, it seems that some factor(s) other than or in addition to lack of cats caused the increase.

Biomass accumulation is a necessary condition for CRP overpopulation. Biomass builds up in a more or less continuous midstorey or subcanopy vegetation layer composed of shrubs, climbers and small non-eucalypt trees which can be indigenous or invasive. Ringtails construct their nests (drey)s in these dense understoreys and then avoid travel on the ground between food trees. Eucalypts above the dense undergrowth or nearby (within 20–30 m) become susceptible. Where there are partial barriers such as roads, phone lines, fences and roofs make excellent connecting routes but powerlines can be deadly. Although exposed, there are no owls to take them and they even fearlessly mate upside down on phone lines in twilight. CRPs don’t build dreys in eucalypt branches and thus require some midstorey. They can use tree hollows but large trees are rare on the Mornington Peninsula and several species compete for their hollows so this behavior is very rare or absent. A CRP preference for structural complexity in habitat to avoid foxes has also been found in East Gippsland.\textsuperscript{149}

As a dense midstorey develops, cats and foxes become irrelevant to adult ringtails. This understorey is a necessary condition for tree decline only because the native aerial and arboreal predators are effectively extinct, as they controlled ringtails in the midstorey and canopy. When the eucalypt canopy is eaten, this midstorey generally thickens with more light, which further assists CRP in a short-term positive feedback loop until they starve.\textsuperscript{150}

What caused the dense understoreys? It took some 30 to 50 years in Mount Eliza for the understoreys to develop in reserves and gardens from the time of residential development from the 1950s to the 1980s. Prior to then, as grazing land, understoreys were kept largely open\textsuperscript{151} presumably by livestock grazing, shrub browsing by wallabies and by fire. Grazing and burning ceased, and as the woodland became fragmented it was harder for wallabies to evade their predators which were by then the fox plus roaming domestic dog.

Foxes and wallabies coexist throughout their broad range overlap in southeast Australia, in extensive native vegetation as well as in remnants down to 90 ha or less, so tipping the balance to local extinction must have involved additional factors such as fragmentation, dogs and roadkill. With roaming domestic dogs added to foxes the predator pressure was artificially high. It is unlikely that direct human disturbance was a major factor since wallabies are common in campgrounds in many national parks in southeast Australia.

The last record of black wallaby in Mount Eliza is from Moorooduc Quarry reserve in 1983.\textsuperscript{152} There was a time lag of decades between urbanisation, loss of the wallaby, the understorey build up and the possum overpopulation. Novel predators (domestic dogs) may be implicated in the tree decline by sending the wallaby extinct. This would not matter if the native aerial and arboreal predators were still there to control ringtails in the resulting dense midstorey vegetation. Only due to the local extinction of these predators do foxes and wallabies come into the tree health picture. Novel predators (dogs) are thus part of the problem and part of the solution (foxes) as there is no other way of controlling ringtails now.
The original grassy woodlands of the northern Mornington Peninsula with the Aboriginal people were much more open than the bushland remnants and gardens of today as shown by annotations on George Smythe's 1841 historical survey plan. This was likely due to Aboriginal burning combined with wallaby browsing and kangaroo grazing.\textsuperscript{153} It is unlikely that wallabies were controlling shrubs in the open woodland on the Moorooduc Plain due to their need for cover from predators, suggesting that fire was an important factor on this plain.

Figure 27. Vegetation of the northwest Mornington Peninsula in the early 1840s

In both forest and woodland, \textit{open} midstoreys are marginal habitat for CRPs due to (a) limited physical shelter and (b) their need to cross ground to change food trees which exposes them to ground predators. This creates a balance between browsing pressure and canopy health which can be seen wherever understoreys are open.

Ringtail possum associated decline (RPAD) is a syndrome of:

1. eucalypts edible to CRP
2. loss of aerial and arboreal predators (owl, quoll etc.)
3. loss of black wallaby (less understorey shrub control)
4. lack of fire (passive management, no fuel/biomass reduction)
5. dense continuous midstorey (fox, cat cannot reach CRP)
6. CRP overpopulation
7. catastrophic tree canopy loss.
Ringtail possum associated decline (RPAD)

Syndrome:

1. eucalypts edible to CRP
2. loss of aerial and arboreal predators
3. loss of black wallaby (less understorey shrub control)
4. lack of fire (passive management, no fuel/biomass reduction)
5. dense continuous midstorey (fox, cat cannot reach CRP)
6. CRP overpopulation
7. catastrophic tree canopy loss

Figure 28. Mornington Peninsula tree decline syndrome

Low or no predator pressure is a necessary condition – if there was high predator pressure there would be no possum overpopulation. A dense midstorey is a new necessary condition assuming the extinct aerial and arboreal predators controlled CRP in dense vegetation. The lack of reports of mammal tree damage in Victoria at the time of European arrival even in areas with dense understoreys suggests they were indeed controlling CRP, although there was little interest in tree damage early on and fewer people to observe it.

Northern Mornington Peninsula: novel ecosystem

Major predators of common ringtail possum (Koori: bemin)

<table>
<thead>
<tr>
<th>Original</th>
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</tr>
</thead>
<tbody>
<tr>
<td>aerial</td>
<td>powerful owl, grey goshawk</td>
</tr>
<tr>
<td>arboreal</td>
<td>lace monitor, spot-tailed quoll, tiger snake</td>
</tr>
<tr>
<td>ground</td>
<td>dingo, Koori</td>
</tr>
</tbody>
</table>

Novel predators

Red fox Vulpes vulpes
Cat Fells catus

- catch possums on the ground changing food trees
- without top predator dingo, mesopredator release may reduce predator-limited fauna populations

Figure 29. Change in predator regime, northern Mornington Peninsula
All major native predators of CRP are extinct or effectively so in Mount Eliza (2 mammals, 2 birds, 2 reptiles). Powerful owls took possums from tree canopies at night. Grey goshawks took possums by day from within trees as did spotted-tailed quolls. Lace monitors were deadly venomous arboreal predators while dingoes took possums on the ground. Occasionally the now possibly extinct tiger snake would climb shrubs and bite and envenomate possums in their dreys and catch them soon after on the ground. Importantly, aerial and arboreal predators are now effectively gone from the predator regime.

Ringtail possums were controlled in both open and dense understoreys under the original predator regime, but with the now simplified predator regime (ground predators only) they are uncontrolled in dense understoreys. This has led to overpopulation, loss of canopy, starvation and ecological collapse. Site extinction is the result for flora and fauna that require either eucalypt trees or full sun at ground level (not shady scrub). When a midstorey becomes continuous, CRP escapes its last predators, the ground-based fox and cat, and undergoes classic irruptive growth followed by a Malthusian check when the food trees are killed.

Locally extinct or endangered aerial and arboreal predators (powerful owl, grey goshawk, spotted-tailed quoll, lace monitor, tiger snake) appear to be missing pieces in a puzzle explaining the possum overpopulation and eucalypt defoliation, which is linked with dense midstoreys.

However, powerful owls alone may not be enough to limit ringtails, as defoliated trees over dense understoreys occur in the owl territories on the southern Mornington Peninsula and in eastern Melbourne. A combination of predators limited CRP in dense vegetation where it occurred, with quolls especially taking many possums in addition to owls. Being midstorey dependent the quoll would occur where the Aboriginal fire interval was prolonged.

Susceptible eucalypts, dense understoreys and no predator pressure coincide on the Mornington Peninsula to produce ringtail possum associated decline (RPAD). Adjacent areas lack at least one of these necessary conditions. For example heathy woodland in Frankston and Cranbourne is unaffected as the dominant coast manna gum is not eaten by possums. Other adjacent areas lack continuous midstoreys. Many areas in Victoria support swamp gum with dense midstoreys\textsuperscript{155} where possums and their predators are both present and in balance.

An appropriate management response in the affected area now is to reopen the understoreys as culling of possums and reintroducing predators are impractical. This also has major benefits for ground layer flora and fauna diversity, which declines under shady scrub. It allows canopy eucalypt recruitment, if there are surviving mature trees, as their seedlings need full sun. It also reduces fire hazards – at present the many bushland remnants are overgrown (see Smythe’s plan), creating the potential for dangerous fires. Weed control in the two years following biomass reduction will ensure that indigenous plants regenerate.

With thousands of dying trees only a limited number of large trees in prominent or strategic locations can be saved by possum bands though this is an appropriate action. Mornington Peninsula Shire has installed possum bands on a large number of trees on roadsides and in reserves. This has been successful except for trees for which it was either too late or their isolation was not effective due to insufficient pruning of adjacent trees.

Does banding trees increase possum pressure on adjacent unprotected trees? Yes it accelerates their decline but if they are edible they will die anyway as the prognosis for the remaining eucalypts is ‘extremely poor’.\textsuperscript{156} In the absence of biomass reduction there are basically two options: protect some trees or lose them all.
Possums feed on remnant indigenous trees where they can, avoiding most but certainly not all planted trees and shrubs. This tends to concentrate browsing pressure. Feeding by people can be a factor, but little or none occurs with ringtail overpopulation as possums are usually seen as a nuisance by locals when it comes to gardens and fruit trees. Human-fed possums still browse on indigenous trees but they leave the least palatable trees to last.

Ringtail possum induced tree decline (RPAD) is by no means restricted to residential areas.

It has been suggested that a dense layer of invasive sweet pittosporum *Pittosporum undulatum* under canopy eucalypts affects them adversely through competition or chemical interaction. However, eucalypts seem to get on with pittosporum as well as with any other competing tree, as can be seen where they occur together naturally in Gippsland. Close observation indicates that the usually unhealthy canopy above dense pittosporum is due to ringtail possum defoliation with the pittosporum providing sites for ringtail dreys.

No allelopathic interaction is known between these genera and treatment with *Pittosporum* leaf-extract actually increases germination in *Eucalyptus viminalis*.

Habitat loss is sometimes suggested as an explanation for ringtail possum overpopulation and tree decline. However the problem is due to habitat alteration and not habitat loss since:

- Ringtail possum overpopulation and tree decline are widespread on the northern Mornington Peninsula in urban and rural areas where there has been no recent clearing in the vicinity, for example in Mount Martha Park, Kirton Reserve, Mount Eliza Regional Park, Earimil Creek Bushland Reserve, and on Walkers and Kunyung Roads, Mount Eliza.

- Adjacent uncleared habitat is saturated with possums so newcomers are unlikely to be accepted and are likely to die as do relocated brushtail possums before they can build or steal a drey to defend. CRPs are quarrelsome although most disputes are resolved by staring competitions. An individual may fight for a drey at the expense of another individual. The habitat is already at or beyond carrying capacity and surplus animals die.

While stands of trees in woodlands with dense midstoreys are vulnerable to ringtail possums, isolated trees in paddocks, gardens and on roadsides are unaffected.

Figure 30. Isolated snow gum not accessed by possums, unbrowsed and healthy, Moorooduc, northern Mornington Peninsula
Ringtail possums are normally reluctant to cross more than 20 metres of ground but will travel up to 30 metres. They avoid fox scent. Early accounts indicate that prior to the fox CRP was often active on the ground, suggesting its now largely arboreal behavior may be an evolutionary response. If ringtails now instinctively avoid more than 20 metres of ground the isolated trees should remain free of ringtails regardless of predator pressure. However at The Briars in Mount Martha without foxes CRPs changed their behaviour to become ground active, reaching trees over 80 metres from shelter, making all trees accessible. Too fast to be genetic, this suggests the early accounts were due to predator loss from Europeans.

According to the trophic model, the current background level of predator pressure is keeping the isolated tree subpopulation healthy, and also makes the biomass reduction of midstoreys a practical management option to save the more closely spaced trees in woodland and forest formations. Biomass reduction (a) reduces physical shelter for possums and (b) forces possums to the ground where most but not all are taken by predators.

Fox and cat background predator pressure is irrelevant to adult ringtails living in continuous midstoreys which leads to their overpopulation, but limits ringtail populations living in interrupted midstoreys where canopies are healthy under sustainable browsing pressure.
Management model

The health of woodlands and forests on the northern Mornington Peninsula and surrounds appears to require biomass reduction coupled with predator pressure, as indicated in the management model to arrest tree decline in Table 5. The ground-based novel predators, foxes and sometimes cats as well, are the only major predators in these modified systems. They are quite effective but they require an interrupted midstorey. With a continuous midstorey possums avoid the ground. Possums are still taken but they are mostly dispersing juveniles evicted by adults up in the trees – until the trees die and starvation forces them down too.

One management pathway in the model has a positive outcome for all management variables, starting by maintaining or creating an interrupted midstorey. Understorey reduction can be through ecological burning or manual ecological thinning of an existing dense midstorey. This is a shift along the management spectrum from passive to active site management, and is a partial reapplication of the Aboriginal land management system.

No midstorey at all is not desirable as many flora and fauna species require midstorey habitat, including ringtail possums in balance. The no midstorey pathway doesn’t actually need predators to protect trees as there are no possums to control, but the system is considerably less diverse without a midstorey and digging rats are now bottom-up controlled.

This predator-prey or trophic management model explains all observations including:

- Defoliated trees recover when banded unless it was too late or isolation was not effective.
- Open unfenced sites with interrupted midstoreys and background fox predator pressure don’t have ringtail possum induced tree decline – they have lightly to moderately browsed canopies with ringtails in balance exerting sustainable browsing pressure. Fox scats with possum bones and hair can be found and are indicators of tree health.
- The Briars is a predator exclosure with an interrupted midstorey and overdownd trees as CRPs changed their behaviour to become more ground active.
- Sites with no midstorey within 30 metres have unbrowsed canopies as there are no CRPs.

Is interruption of the midstorey sufficient, making predators redundant if ringtails maintain territories that are large enough to sustain the trees through aggression, with excess individuals banished to die on the ground from stress, starvation or predators? No, because possum density potentially grows to 16 possums per hectare. 162

With the trophic model the answer to the tree decline is simple and effective: thin the understorey and the decline will stop, if foxes are there. Ringtail possums will be back in balance since there is less physical shelter, more predation and possum avoidance of open understoreys. Alternatively remove the understorey entirely and there will be no shelter for ringtails, making foxes redundant but this has adverse consequences for other species.

This doesn’t require any more foxes than now exist, which means maintaining the status quo of no fox control in most areas, while fox removal if it were to occur would make understorey reduction ineffective as demonstrated by The Briars. Foxes have replaced the original predators and are now required in a predator-prey balance with ringtail possums. Fox control should be considered to protect fauna on the state threatened list, but none are in the area.
### Table 5. Trophic management model for woodland and forest on the northern Mornington Peninsula and surrounds

<table>
<thead>
<tr>
<th>Midstorey</th>
<th>Predator</th>
<th>Possum</th>
<th>Canopy</th>
<th>Ground layer</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>continuous midstorey (CRP shelter)</td>
<td>predator</td>
<td>possum overpopulation</td>
<td>no canopy</td>
<td>no ground layer</td>
<td>Kirton Reserve, Mornington</td>
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<td></td>
<td>no predator</td>
<td>possum overpopulation</td>
<td>no canopy</td>
<td>no ground layer</td>
<td>RBG Cranbourne</td>
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<tr>
<td>interrupted midstorey (some CRP shelter)</td>
<td>predator</td>
<td>possums in balance</td>
<td>canopy</td>
<td>ground layer</td>
<td>Woods Reserve, Tuerong</td>
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<tr>
<td></td>
<td>no predator</td>
<td>possum overpopulation</td>
<td>no canopy</td>
<td>ground layer</td>
<td>The Briars, Mount Martha</td>
</tr>
<tr>
<td>no midstorey (no CRP shelter)</td>
<td>predator</td>
<td>no possum</td>
<td>canopy</td>
<td>ground layer</td>
<td>widespread on grazing farmland</td>
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<tr>
<td></td>
<td>no predator</td>
<td>no possum</td>
<td>canopy</td>
<td>ground layer</td>
<td>RBG Cranbourne</td>
</tr>
</tbody>
</table>

**One management pathway has a positive outcome for all management variables**

- **CRP shelter**: common ringtail possum physical shelter
- **predator**: novel ground predators, mainly fox, functioning without extinct native arboreal and aerial predators
- **possum**: common ringtail possum
- **no possum**: no midstorey flora and fauna (many species including CRP)
- **no ground layer**: little or no ground layer flora and fauna due to shade and organic litter smothering from midstorey

macropods (black wallaby, eastern grey kangaroo) largely absent
Understorey reduction is identified as a management option to reduce ringtail habitat quality and increase the risk of predation in the Mornington Peninsula Shire consultant study.\textsuperscript{163} It has been applied successfully in Frankston putting an immediate stop to canopy loss. The recovery of trees was not due to release from competition with the midstorey: the trees were previously eaten back by possums and were not otherwise sick, as indicated by healthy foliage on pendant branches. Here it was a weed species, sallow wattle, being removed but indigenous midstorey species are also problematic.

Opening the understorey creates open habitat for light demanding flora and fauna that barely survive in gaps, beside tracks or on slash breaks if at all. Light demanding species are the majority of species in grassy woodland. Native biomass can suppress biodiversity just as much as weed biomass. Impressive wildflower displays can follow understorey reduction.

This is not a radical solution. Smythe’s 1841 survey (Figure 27) shows that understorey were mostly open at the time of European arrival so the currently dense understoreys are recent. The practical solution to tree decline is to restore the original open understorey.

The understorey can be physically thinned though this is labour intensive. Burning the midstorey scrub has further benefits such as stimulating seed bank germination and plant recruitment, releasing accumulated soil nitrogen\textsuperscript{164} and increasing cost-effectiveness.

However experience shows that where black wallaby is extinct the resulting dense shrubby fire regrowth will not be browsed. Out of control, shrub regrowth soon crashes site diversity and needs manual ecological thinning within five years. Another option is a double burn involving a second fire within a few years before the shrubs mature. The Aboriginal people presumably knew about this effective means of shrub control.
Trees in RPAD critical condition may not respond well to fire as they are pre-weakened by overbrowsing and fuel loads are very and unnaturally high. It may be better to avoid potential harm to these trees by manual thinning of dense midstoreys. Once the low biomass understorey is recreated, surface fire should be safe for the recovered trees to use thereafter. Where macropods are absent there is full reliance on fire and/or ecological thinning for biomass reduction to protect the trees and maintain biodiversity.

Culling is a practical but temporary option in small areas only and it is impractical to reintroduce native predators. Relocation of possums is not a humane option as relocated ringtail possums are likely to die as do relocated brushtail possums.\textsuperscript{165} Release of ‘rescued’ possums into already saturated habitat only increases animal suffering. This leaves habitat manipulation as the only effective means of preventing tree decline over large areas.

Selected trees in bushland reserves and on private land have been banded in considerable numbers but this is a ‘band aid’ solution although it can be appropriate in some situations. Not all trees can be banded due to its cost, impracticality and ridiculous appearance. Furthermore plastic bands last only 5–10 years due to plastic breakdown and metal bands need replacing due to tree growth. A longer term ecological solution is needed: understorey reduction, by manual means or by using fire, is the only cost-effective solution to tree decline.

**Mornington Peninsula Shire response**

Mornington Peninsula Shire is responding to the possum problem by protecting key trees and through public education, in partnership with the Mount Eliza Association for Environmental Care. The following is from the media release of July 2014:\textsuperscript{166}

**Protecting possum-damaged trees**

Recent investigation of trees in Mount Eliza has identified cases of tree foliage damage caused by possum feeding... Mornington Peninsula Shire in partnership with Mount Eliza Association for Environmental Care is taking steps to protect key trees in the Mount Eliza area from over-feeding by possums, as well as offering specially grown seedlings to residents who have lost trees due to possum damage... The Shire is currently placing a band around the trunks of some key vulnerable trees, and pruning select branches to minimise damage to key street trees and some groups of trees in reserves. This program has proven to be very effective...

**Public perception**

While the general public in Mount Eliza is aware that ringtail possums are the main cause of the tree decline, a small number of deniers refute this.\textsuperscript{167} They don’t live in the area to see the possums in action and don’t understand the problem. They say tree decline has many causes, that it is multi-factorial. The Shire’s study\textsuperscript{168} and possum banding of trees have shown that the multi-factors are essentially daddy possum, mummy possum and baby possum. To not diagnose the problem correctly is to delay action which could cost the remaining trees.

**Media coverage**

Possum induced tree decline has received considerable local media attention, with several articles and letters in local newspapers including the *Mornington Peninsula Leader* (16 and 30 April 2013), and the *Mornington News* (17 and 24 November 2015, and 1 December 2015). For a summary and the most recent article see Appendix 2.
Tips on installing possum bands

The following guidelines are based on extensive experience with possum bands:

1. Protect trees in poor or critical condition, terminal condition is too late.
2. Protect dominant canopy trees, not subdominant trees that will die naturally anyway.
3. Remove connections, possums can jump 2.5 metres.
4. Clear plastic and self tapper screws are suitable materials.
5. Alternative more durable materials are metal and pop rivets.
6. Ensure possums cannot get under band.
7. Employ an arborist if climbing is required.
8. Band may require replacement within 5 years due to plastic breakdown or tree growth.
9. Damaged trees can be regenerated by cutting at ground level for coppice regrowth.
10. State or local government agency to protect trees on public land.

The quality of possum banding is an issue. Some trees on public land have been banded too late or were not isolated by removing connections, with continued overbrowsing leading to tree death. Mornington Peninsula Shire has changed contractor. The problem seldom happens on private land as installers are more accountable there.

Figure 32. Expert arborist installing possum band on large manna gum, adjacent planted spotted gums *Corymbia maculosa* and many other non-indigenous trees are not eaten by possums

*It’s quite a buzz to save a 200 year-old tree with a piece of plastic!*
Swamp rat

The swamp rat *Rattus lutreolus* is a native specialist herbivorous rat of eastern Australia. It feeds on the basal shoots and stems, rhizomes and other below ground storage organs of monocotyledons including geophytes. This rat is by no means restricted to swamps.

Major factors controlling population sizes are predators which were originally mainly dingoes, snakes, quolls and owls and are now mainly foxes and cats in modified ecosystems, food supply, fire and availability of shelter. Swamp rats are cover dependent which is an adaptation against predators. They need dense ground layer vegetation in which to make their nests and runways and find food, and are reluctant to venture into the open even for food.

Swamp rats control rhizomic plants with the potential for overdominance such as thatch saw-sedge *Gahnia radula* and thus play a beneficial ecological role in bushland. But by digging up and eating tubers, they can deplete or eliminate orchids such as common bird-orchid *Chiloglottis valida*, dainty wasp-orchid *Chiloglottis trapeziformis*, purple diuris *Diuris punctata* and nodding greenhood *Pterostylis nutans*.

In recent years on the Mornington Peninsula, numerous orchid colonies in several locations that were tended for many years by land managers and volunteers have been devastated by increased swamp rat numbers/activity. Locations include Mount Eliza (three reserves), Mount Martha (three reserves) and Rosebud (two reserves). Orchids are too rare to be staple diet items so the rats rely on common food sources such as introduced onion-grass *Romulea rosea*. But once an orchid colony is discovered it is dug up and eaten.

Orchid losses are alarming especially in isolated areas where there is less potential for recolonisation. Losses have necessitated wire mesh guards at several locations to protect the remaining tubers. Wire mesh guards have their own problems: they attract attention from people, impede access for biomass reduction and weed control, and prevent access by blue-tongue lizards which control invertebrate predators of orchids.

Swamp rat numbers may increase with high rainfall due to increased food supply\(^{169}\) and the increased rat numbers/activity coincides with the 2010–2012 La Niñas. However orchid colonies were healthy and unaffected by rats during previous La Niñas and successive years of high rainfall such as 1991–93.\(^{170}\) Rainfall alone does not explain the losses.
An increase in swamp rat numbers/activity has caused the unprecedented orchid losses. Unprecedented major environmental changes may be involved including:

- ground layer and shrub biomass build up due to
  (a) stimulation by La Niñas
  (b) gradual accumulation over time without fire
  (c) increased shrub cover on small burn sites
  (d) removal of invasive shrubs leading to denser ground layer
  (e) more light due to ringtail possum induced tree canopy loss,

- intensive annual fox and cat control in 10–15 bushland reserves each year commencing in 2007.

Both factors may increase rat numbers but their relative contributions are not clear. No obvious increase in ground layer biomass was noted at Earimil Creek Bushland Reserve in Mount Eliza around the time of increased swamp rat activity and orchid depletions in 2012. There are no data on fox and swamp rat numbers as they and the orchid colonies have not been monitored. Research including camera trapping is needed for orchid conservation.

A pattern has emerged from site observations on the Mornington Peninsula, that where feeding/breeding conditions for swamp rats are optimised with an absence of a sufficient predator species suite then the probability of geophyte depletion is increased. This ecological phenomenon appears to be both predictable and preventable. In contrast, bush rats did not undergo a population increase with fox removal in one study.

Relationships between native rats (swamp rat, bush rat) and introduced rats (brown rat, black rat) are not clear. Black rats are aggressive to swamp rats and are sometimes trapped by land managers, which presumably assists swamp rats. Black rats are generalist omnivores and scavengers, but they can dig extensively and it is not clear how much impact they have. Curiously, bush rat is considered to be absent from the Peninsula.

The absence of snakes in many urban bushland reserves means less predator pressure on native and introduced rats. With the lack of predators now almost complete the rats are likely to undergo ecological release with population sizes controlled more by food supply than predation. The widespread loss of snakes in Melbourne and Mornington Peninsula bushland may be related to past and present predation on juveniles by domestic cats. Cats prey on snakes and there are many media reports of domestic cats killing and being bitten by snakes. ‘It’s the cats that we tend to see which have more of those interactions [with snakes] than the dogs’. As an area becomes urbanised, the adult snakes may live for many years in remnants but they eventually die without being replaced by recruits. Snakes leaving remnants in search of food or mates only to be caught or killed would also deplete numbers.

The questions that land managers throughout the wide range of digging rats need to answer are ‘what is the most effective and efficient method to maintain geophyte diversity?’ and ‘what is controlling digging rat numbers?’ Basic ecology suggests that if it is not predation then it will be other biotic factors such as competition or starvation, or physical factors such as drought, fire and availability of shelter. Starvation of rats has dire consequences for geophytes, particularly where habitats are fragmented and recolonisation potential is limited.
Case studies – sites

The following case studies explore native mammal herbivore imbalance at selected sites in central Victoria.

Royal Botanic Gardens Cranbourne

The Royal Botanic Gardens Cranbourne southeast of Melbourne is an experiment in predator exclusion gone wrong. Foxes and cats have been excluded from 250 ha of bushland by a predator fence to protect southern brown bandicoot since 2003. Bandicoots are now delightfully and unnaturally abundant, but they were common before the fence due to dense heathy woodland providing sufficient shelter from foxes and previously quolls et al.

In the heathy woodland section, tree canopy health is not affected by possums even though shrub shelter is ample for ringtails. Possum density is naturally low due to inedible coast manna gum Eucalyptus viminalis subsp. pryoriana.

In the grassy woodland, small areas of dead narrow-leaf peppermint Eucalyptus radiata have possum defoliated trees on their margins. This appears to be the widespread ringtail possum associated decline (RPAD) syndrome which does not relate to the predator fence. Much of the existing peppermint canopy is browsed but coping. This is likely due to low ringtail density with limited midstorey cover and low brushtail density with limited tree hollows. Management burns further reduce the midstorey, giving trees more respite.

The possum populations at Cranbourne are bottom-up or habitat controlled: low food quality limits numbers in heathy woodland, and limited physical shelter limits numbers in grassy woodland. The grassy woodland tree canopy would be at risk if shrubs were to increase. Ironically the wallabies inhibit shrub recruitment and indirectly protect the trees.

Without foxes the wallaby population has exploded, resulting in a loss of plant diversity which undermines the purpose of the gardens. The vegetation looks drab and species-poor even in spring where previously it had impressive shrubby wildflower displays. Managers are responding by opening the wombat gates to allow the starving wallabies out but numbers remain stubbornly high as there is limited habitat outside. This means foxes now enter the site and are being controlled on the inside, making the fence redundant.

There is talk of removing the fence to normalise wallaby numbers. This would return system predator pressure and should result in stable and sustainable populations of foxes, wallabies and bandicoots, as previously. This is the least expensive and most ecological option.

Phillip Island

Ecosystem consequences of vertebrate predator removal are at a landscape scale in remnant woodlands on Phillip Island, with canopy dominant trees manna gum and swamp gum in massive decline from possum overbrowsing. Possums are introduced to the island. Foxes have been intensively controlled in recent years throughout the 100 km² island.

Canopy damage and tree loss with characteristic defoliation and abundant possum scats are evident on sites that had healthy trees before the elimination of foxes. Fortunately indigenous southern blue gum Eucalyptus globulus and introduced coast manna gum are not eaten by possums and remain healthy. Black wallabies and rabbits are also overabundant and damaging the island. Koalas are introduced to the island and are declining from reproductive failure more than predators. Fox and cat control is appropriate in localised areas such as the penguin colonies at the western end of the island, at considerably less ecological cost.
Mount Eliza escarpment

While the original grassy woodlands of the northern Mornington Peninsula had open understoreys, the isolated forest on the edge of the plateau of Mount Eliza and its steep cool southeasterly aspect escarpment may have had a dense understorey. The annotation on Smythe's survey ‘forest land clay soil very scrubby no grass’ (Figure 27) applies to the plateau and some of the escarpment. The clay soil was clearly soil developed on the restricted Ordovician sandstone, slate and chert which include most of the escarpment.176

The Mount Eliza escarpment faces inland and naturally supports a mixed eucalypt woodland of manna gum, narrow-leaf peppermint and swamp gum with an isolated occurrence of more rainfall-dependent messmate stringybark on one south aspect slope and the plateau above. Blackwood and other woody plants form a dense midstorey where locally abundant.

Spot-tailed quoll is dependent on dense vegetation177 being ‘dispersed over the thick bush’ in the Melbourne area.178 Indeed quolls were on the escarpment. They were eliminated during sweeps by chicken farmers from the Moorooduc Plain below in the 1930s.179 The timing indicates STQ since from about 1910 only three isolated populations of eastern quoll were known in Victoria (none on the Peninsula) following the mysterious epidemic of 1901–03 which annihilated many marsupials in Victoria.180,181 The quoll and powerful owl were presumably the major predators of CRP in the dense midstorey and canopy.

Historical aerial photography indicates that in 1937 logging and clearing of the escarpment had recently commenced,182 but many large old trees remained and the canopy was healthy on the escarpment and plateau. The abundance of large old trees suggests that ringtails were in balance in Smythe's scruffy forest, as many of the old trees would have been alive in 1841. Today the area is undergoing massive eucalypt tree loss from possum overbrowsing.

The Briars

The Briars in rural Mount Martha is a 95 ha woodland ecosystem accidentally thrown into crisis by an electric predator fence constructed in 2013. After decades of stability and a healthy tree canopy, predator exclusion has rapidly led to major canopy damage and tree loss from CRP and CBP irruption. This is despite a largely interrupted midstorey. Diagnostic possum damage symptoms are everywhere and scats of both species are highly abundant.

Defoliated tree species include narrow-leaf peppermint, swamp gum, snow gum, drooping sheoak, black sheoak, silver banksia and sweet bursaria. The severity of damage is masked in the northern area by a subpopulation of the resistant genotype of manna gum, while the susceptible genotype is being picked off everywhere. While severe inside the exclosure, in adjacent bushland overbrowsing is minimal except for South East Water land where foxes are actively controlled and overbrowsing is also evident. Overabundant swamp rats and rabbits are also destroying reserve features such as greenhood orchid colonies beside walking tracks. It is clear from the Briars that fox control in novel bushland can be a very bad idea indeed.

While The Briars is becoming a tree graveyard, it does reveal something important about ringtails: without foxes they rapidly change behavior and become more ground active as do brushtails. They readily travel over 80 metres across ground from their dreys in shrubs, whereas 30 metres is the usual limit in the normal presence of foxes. This is relevant to management: creating an interrupted midstorey to save trees works only if there are foxes to take possums on the ground changing food trees. Otherwise all edible trees are accessed and eaten, even previously healthy large old peppermints out in the open such as at The Briars. This is useful knowledge in formulating a trophic management model to arrest tree decline.
Discussion

Role of predators

Each natural ecosystem with vertebrate herbivores has corresponding vertebrate predators. It is clear they hunt not only the old and weak but also the breeding adults and/or young of their prey which keeps herbivore populations down. They also influence prey habitat use pattern and behavior by creating a ‘landscape of fear’. The result is more resources including trees, shrubs and ground layers to share and thus better survival for most species.

Predators stabilise ecosystems in southeast Australia but not where the novel megaherbivores deer and horses are increasing without their megapredators. Sambar (deer) are spreading on the mainland and dingoes are not keeping pace. Dingo packs predate on sambar, usually on calves, but they are difficult prey compared to macropods. Large dingo and sambar populations can occur together with dingoes feeding on deer carrion left by human hunters.

Novel predators have partly replaced the native predators, but with only three species they don’t make up for the loss in native diversity. Despite this the fox is now surrogate top ground predator over large areas where the dingo is absent and is ecologically net positive. Novel predator pressure on native and novel herbivores is so pervasive and continual that it is seldom noticed except when it is gone. This is clear since every predator enclosure in the region has experienced major herbivore imbalance be it from rabbits to kangaroos.

Experience with exclosures indicates that without novel predators herbivores would be far more abundant and damaging to ecosystems everywhere. For example at Mt Rothwell rabbits had severely grazed the understorey in 2014 leaving much bare ground, and brushtail possums were overbrowsing the eucalypt canopy except for red box which is resistant to possums.

Novel predator pressure is a major factor limiting populations of several novel herbivores and omnivores including goat, rabbit, brown rat, black rat and house mouse. Where this pressure is reduced by exclosures or control action these pest species increase, with adverse effects.

The profound influence of predators is apparent upon site inspection, with animal scats and levels of browsing, grazing and digging being key indicators. Barbara Triggs’ guide to mammal tracks, scats and other traces takes on added importance. You can ‘read the bush’ and see the influence of individual predator and herbivore species.

Whether the predators or prey are native or novel during trophic imbalance makes little difference to overall biodiversity – overabundant herbivores degrade ecosystems. Current land management is pushing systems towards domination by browsing and grazing mammals, with other influences such as predation and regular fire being reduced.

Wherever there is no vertebrate herbivore overpopulation causing major vegetation cover loss, which is much of the region, this is likely due to inedible vegetation or various vertebrate predator-prey balances in operation coupled with disease and physical factors. In more human-modified areas the predators are the familiar novel predators. Ecosystems are stable over large areas where novel predator pressure compensates for the drop in native predator pressure. Predator pressure continues with the novel predators able to survive near humans.

A global review of predator-prey manipulation experiments found alien predators to be more harmful to prey populations than native predators, and they ‘can impose more intense suppression on remnant populations of native species and hold them further from their predator-free densities than do native predators preying upon coexisting prey.’
This is presumably so in many cases, but the original predator regime of southeast Australia is not there to compare even in East Gippsland (eastern quoll is missing), and the only predator-prey relationships included from southeast Australia are bush rats and kangaroos.

In particular, bush rat didn’t benefit from fox control\textsuperscript{188} while eastern grey kangaroo did.\textsuperscript{189} Neither study could reproduce the original predator regime, so full comparison between native and introduced predators was not made. Neither prey species is threatened and kangaroos actually require predator control as shown by their overabundance within predator exclosures. The review includes only one of seven potentially problematic native mammal herbivores, the kangaroo, and does not extend to novel herbivores such as deer, goats and rabbits. Relationships between fauna and their vegetation habitat are not considered.

Each ecosystem is composed of hundreds or thousands of species. Grassy woodland for example has over 100 vertebrates and 200 vascular plants including native and novel species. At the centre (or top) is a small set of vertebrate predators and herbivores. The stability of this group is vital for system diversity. When this group is put out of balance by human induced predator loss, the herbivores can increase to destroy trees, shrubs and ground layer resulting in most species going site extinct. Without human interference, predators prevent herbivore imbalance and always have. What we see as stable bushland is predator dependent.

Ecosystems with no vertebrate herbivores have no corresponding predators, for example the unique Mud Islands in Port Phillip Bay where barn owls, swamp harriers and whistling kites are the top predators preying on breeding seabirds and/or waterbirds.\textsuperscript{190,191} In a bizarre predator-prey-vegetation interaction, barn owls \textit{Tyto alba} are likely to prey on white-faced storm-petrels \textit{Pelagodroma marina} whose burrowing activity kills patches of coast saltbush \textit{Atriplex cinerea} shrubland on sand dunes. Similarly, areas above the tree line (alpine areas) lack native vertebrate herbivores and corresponding predators and have very unusual ecology.

\textit{Top predators}

There is compelling evidence that apex or top predators maintain ecosystem structure and function by regulating trophic cascades globally.\textsuperscript{192,193} Top predators have far reaching influence on ecosystems. Removal of a top predator can start a negative trophic cascade with system disruption that may include loss of species, reduced vegetation cover, tree canopy loss and accelerated erosion, and may extend all the way down to the soil nutrient pool.\textsuperscript{194}

Top predators are largely bottom-up controlled by their prey density and abundance. However, infraspecific aggression, habitat disturbance and persecution by humans can reduce their density to below habitat carrying capacity and mesopredators take their place.

In southeast Australia the top predator human previously preyed on thylacines, dingoes and devils. These then mesopredators and the humans preyed mainly on macropods (kangaroos and wallabies), koalas and possums. Collectively the predators had the herbivores covered. When Aboriginal hunting effectively ended in southeast Australia the dingo was promoted to surrogate top predator within its mainland range which contracted due to persecution.

There is no full replacement for the dingo. Victoria’s mysterious ‘large cat’ may be just \textit{Felis catus} but further DNA evidence is required.\textsuperscript{195} In modified ecosystems without the dingo, the fox is a surrogate top predator but may not be a true top predator due to mesopredator release which increases its numbers and lowers prey populations. Predator exclosures reveal systems are even worse off without the fox.
**Mesopredator release**

A feature of Australian novel mesopredators is their apparently higher predation rates on certain native prey compared to native predators, for example the red fox appears to have eliminated the rufous-bellied pademelon on mainland Australia. Reasons for increased predation are likely to include prey naivety\(^{196}\) and mesopredator release\(^ {197}\). Where the dingo is absent, mesopredator release of the fox appears to operate, with more foxes and more predation on small prey species than if dingoes were there controlling foxes.\(^ {198,199}\) Mesopredator release of the red fox also occurs in North America without coyotes.\(^ {200}\)

Outside the arid zone 5,600 km dingo fence, for example, uncontrolled dingoes appear to suppress fox populations which assists small to medium native mammals.\(^ {201}\) Similarly, there is evidence from southeast Australia that dingoes suppress macropods and foxes and thus have strong indirect benefits for the prey of foxes.\(^ {202}\)

A predator manipulation experiment in semiarid Western Australia\(^ {203}\) found that when dingoes and foxes were both removed cats increased and predation on small mammals increased further, suggesting a hierarchy of predators (dingo, fox, cat) and mesopredator release processes. As the study comments, this needs replication. The evidence for an increase in cat abundance following fox control is inconsistent, and there is also limited knowledge on the impacts of feral cats and foxes on native predators.\(^ {204}\) Interactions between predators such as aggression, competition for prey and predation on juveniles need research.

Mesopredator release can have far reaching trophic cascade effects. One cross dingo fence study links the loss of the canine apex predator to shrub encroachment in semiarid South Australia and New South Wales. Loss of dingoes allows foxes and cats to thrive and prey on small native and novel seed-eating mammals such as dusty hopping-mouse and house mouse. This has led to a rapid spread of native hopbush shrubs which threaten livestock farming.\(^ {205}\)

The fox mesopredator release hypothesis is used to support dingo conservation, but a review found that most (15/20) of the relevant dingo studies contain methodology flaws and cautioned that the evidence is inconclusive.\(^ {206}\) Debate is ongoing.\(^ {207,208}\) It is also possible the dingo is itself undergoing mesopredator release without Aboriginal hunting.

Mesopredator release can also occur in native fauna. Inside the Mulligans Flat predator exclosure echidnas of all things are building to unsustainable numbers and managers are considering reintroducing goannas and snakes to prey on their juveniles.\(^ {209}\)

Mesopredator release is also documented for Australian islands where ‘eradication of introduced apex predators (cats, foxes or dingoes)... could precipitate the expansion of black rat populations, potentially leading to extinction of native mammal species whose remaining populations are confined to islands’.\(^ {210}\) Rat mesopredators are worse than cats and foxes.

**Herbivore release**

Any drop in predator pressure causes some degree of herbivore and/or omnivore release. Humans are the usual cause, either directly by killing predators, or indirectly though habitat loss or alteration which excludes predators. Habitat loss can take the form of clearing native vegetation with large hollow trees providing vital shelter for goannas. Habitat alteration can occur as overgrown understoreys which allow possums to avoid ground predators, or arrival of the cane toad which kills goannas resulting in higher populations of crimson finches.\(^ {211}\)
Herbivore release changes the population sizes of most or all flora and fauna in an ecosystem through trophic cascades, starting with the herbivore and its food plants. As populations adjust to the herbivore increase, some may dip to zero. Herbivore release becomes herbivore imbalance where there are site extinctions. Herbivore imbalance is severe or catastrophic where it affects large areas especially if there is accelerated erosion or tree canopy loss.

**Threatened wildlife**

Alien predators, including cats, rats, foxes and house mice, threaten fauna globally, particularly on islands, and alien predators are considered more harmful than native predators. These aliens have a devastating impact on a range of fauna as they integrate into novel ecosystems. But predator exclusions in southeast Australia show that without native predators the surviving fauna then rely on these replacement predators to control herbivores.

It is widely accepted that alien predators have caused the decline of many native fauna in Australia, mostly ground-living marsupials in the ‘critical weight range’ of 35–550 grams in the arid zone outside southeast Australia. This is largely due to these medium-sized animals being likely to be more exposed to predators in open habitats. But how does predator pressure in the more densely vegetated southeast Australia differ now from originally?

The native predator regimes of southeast Australia were lost or disrupted before scientific recording which makes observation and experiment difficult now. Certainly the natives applied major system predator pressure – enough to control and regulate their prey. Local extinction is predisposed by fragmentation which is either natural or due to land clearing. Would the native predators if they were still there also threaten fragmented populations?

The numbers of native wildlife taken by feral cats and foxes are often stated but are difficult to verify. Regardless of the actual number, it should be noted that the progeny of herbivores must succumb to some form of mortality or there would be a vast overabundance of herbivores. An average female ringtail possum typically produces some 10 progeny during her lifetime, based on average longevity and litter size and frequency. In a stable population she will produce only 2 mature offspring in her lifetime. Similarly, a female swamp rat produces some 20 progeny of which 18 die young in a stable ecosystem.

Is it not better that the doomed surplus herbivores die quickly in the jaws of a predator, as has been happening for millions of years, rather than slowly through stress and starvation after damage is done to the ecosystem? Predation is a natural process, so aggregate figures on the numbers of wildlife taken by predators are not necessarily alarming from an ecological perspective, since the removal of excess animals is essential in stable ecosystems. What matters more is the population size and stability of any threatened native fauna.

A study of foxes in south-west Australia concluded that fox suppression of native fauna populations is so severe that fox control is worthwhile everywhere. Foxes and cats were both removed from treatment sites so their relative contribution to predator pressure was not clear. Dingoes were absent so how much was fox versus mesopredator release is also unclear.

And yet a detailed long-term study of the fox diet in southeast Australia found that listed native species of conservation significance occurred at low frequencies (<0.2%) in scats except for broad-toothed rat (1.5%). Foxes were mainly eating pest animals especially rabbits and native herbivores that require control such as possums. The fox is a double-edged sword, a direct threat to some species but of indirect benefit to others.
**Appropriate predator control**

Novel predator control may assist endangered native predators and so should be considered where they occur together, the natives having higher conservation priority. There is a balancing act between promoting these natives and maintaining system predator pressure. If the native predators can recover then native herbivores may return to sustainable levels.

Predator control is warranted to protect other predator-limited threatened native prey species such as brush-tailed rock-wallaby and mountain pygmy-possum. All potential prey will benefit but herbivore control may be appropriate with the drop in predator pressure.

Foxes disperse weed seeds and probably native plant seeds as well. Blackberry *Rubus fruticosus* spp. agg. is spread by internal transport (foxes eat the fruit)\(^{219}\) and cleavers *Galium aparine* is spread by external transport (on fur). Fox control may reduce the incidence of blackberry but birds are also important dispersal vectors.

Blue-tongue lizards and snakes are preyed on by novel predators (previously by native predators), so predator control may increase their populations. The habitat carrying capacity for these reptiles in terms of food supply may not be reached due to high peri-urban predator pressure, which can endanger local populations in part due to small population size. By searching every square metre for invertebrate herbivores such as garden snail *Helix aspersa*, blue-tongues are keystone species for many orchids and other plants such as button everlasting *Coronidium scorpoides*. However, if possums can destroy the tree canopy fox control is not worthwhile and a smaller blue-tongue lizard population is a necessary cost.

**Inappropriate predator control**

Novel predators can be overrated as pest animals in novel ecosystems and their control is sometimes pointless or counterproductive. All native fauna have defensive adaptations against predators, with many effective against the fox. One study found for example that malleefowls did not benefit from fox baiting, providing a ‘powerful example of why management decisions should be based on evidence, rather than ecological intuition’.\(^{220}\)

Always regarding the fox as a pest animal can lead to blinkered and poor management decisions which may threaten the health of woodland trees and ecosystems. For example in a conservation management newsletter from the northern plain of Victoria it is ironic that land managers congratulate themselves on fox control in reserves and wonder why brushtails are ‘causing havoc’ in red gum woodlands – in different articles in same issue.\(^{221}\)

Fox control can have unexpected trophic cascade effects, for example it led to local extinction of greater glider *Petauroides volans* in Booderee National Park. This was due to consequent increases in ringtail and brushtail possums which led to an influx of powerful owls and a shortage of tree hollows which were occupied by larger numbers of brushtail possums.\(^{222}\)

Most fox control effort does not have a significant effect on the fox population to alleviate impacts.\(^{223}\) Furthermore the ‘hydra effect’ has been found in dingo, fox and cat control, meaning that episodic control increases the density of the target species. For example, researchers searched a 2000 ha property in central Victoria for breeding fox dens and found 13. Soon after, they undertook intensive control on the property (shooting, poisoning, trapping) and removed fifty foxes and twenty-one feral cats. Eight months later (the next fox breeding season) they counted 17 active fox dens.\(^{224}\) Similarly, shooting and trapping feral cats increased cat density in Tasmania.\(^{225}\) The hydra effect is worldwide and is caused when a dominant animal is removed and subordinates start to breed or come in to explore the vacant territory.\(^{226}\) The alternative of continual intensive predator control is expensive.
Tasmania

Comparison between Victoria and Tasmania indicates the impacts of the dingo and fox on the fauna of mainland southeast Australia. Neither species has reached or established in Tasmania. Clearly the fox has had more impact than the dingo.

The arrival of the social dingo on the mainland meant the loss of the more solitary thylacine and devil, another possible loser being the flightless Tasmanian swamp hen. Clearly the fox has had more impact than the dingo. Other native species may have permanently lower populations.

The later fox has caused the loss of many more mammals in arid and semiarid Australia. However only three have been lost on the moist coastal fall of mainland southeast Australia: rufous-bellied pademelon – a herbivore, southern bettong – an omnivore, and eastern barred bandicoot – an omnivore. They still occur in Tasmania. Mountain pygmy-possum and brush-tailed rock-wallaby survive but are critically endangered by foxes, and some other species are partly endangered. How much of this impact was/is prey naivety or mesopredator release is unclear since the dingo was eliminated early in most areas.

This experience suggests that if the fox were to establish in Tasmania the pademelon, bettong and bandicoot would go completely extinct. However the devil is thought to enter fox dens and eat the cubs, so as a keystone predator its recovery from the facial tumour disease epidemic may be vital for these and other species. Fortunately it has evolved resistance to the disease in just four to six generations. This provides a potential reason to reintroduce healthy devils to mainland Australia, at least where dingoes are absent.

Climate change

Heat waves over 40°C can be deadly to common ringtail possum due to physiological limits and the prolonged exposure of its drey to hot dry northerlies. Common brushtail possum is a better survivor in its protected hollow. Global warming as predicted will increase the frequency of such heat waves and thus increase the overall mortality rate, possibly in all species. Whether the predators or herbivores survive best remains to be seen.

Fire

Fire is a major factor along with predation controlling herbivore pressure in ecosystems. Could fire alone maintain diversity by controlling herbivores? The relative contribution of fire and predators depends on fire regime and herbivore. Kangaroos can escape fire so predation by humans and dingoes must have been significant once. Extensive fire may eliminate or reduce ringtail possums until a midstorey redevelops, wallabies until shrub cover redevelops, or swamp rats until ground cover is restored, but these are temporary effects. Also, herbivores can commute in and eat the regeneration if the fire is small in area.

The Aboriginal people imposed a fire regime for animal production, plant production and access. Fire was skillfully used to flush prey such as kangaroos or brushtail possums and to create fresh regrowth attractive to prey. Aboriginal burning produced an intricate fine-scale mosaic of vegetation age classes and was in part a human predator strategy. The absence of this particular form of predator pressure contributes to herbivore imbalance.

Fire may need to be extensive and/or frequent to keep herbivore levels down in the long term. This may not be practicable or sustainable in terms of fuel levels let alone effects on biodiversity, leaving continual predator pressure as an efficient and targeted control factor.
A notable predator-herbivore-plant relationship is between predators, black wallaby and austral indigo *Indigofera australis* which is a widespread shrub. *Indigofera* can be killed by fire or can resprout from the base. Seedlings germinate from the soil seed bank after fire. Coppicing shrubs and seedlings are vulnerable to wallabies as they are below the wallaby browse line (about one metre) and, if the burnt area is small, surrounding wallabies can focus on the species. Local survival can depend on inaccessible cliffs acting as refugia. *Indigofera* benefits from the rare ecological release provided by a fire so extensive that it kills or expels wallabies over tens of square kilometres. Seedlings grows rapidly to exceed browse height before wallabies recolonise, flower in their second spring and replenish the seed bank. An example is the 1983 Ash Wednesday fire regrowth at Anglesea. A fine-scale fire mosaic is not optimal for *Indigofera* but it survives in many areas as wallabies are also under control.

**Rewilding**

According to proponents, ‘rewilding’ with apex predators has benefits for ecosystem stability and diversity. The predators are either regionally extinct or are related to extinct Pleistocene predators. For example Komodo dragon could replace the similar *Megalania* in order to control feral water buffalo in northern Australia. Replacing extinct marsupial megapredators with placental megapredators such as large cats would be controversial, even if they could provide further means of controlling camels, horses, deer, pigs and goats. Ecologically released megaherbivores are increasing and highly damaging in Australia as they are largely bottom-up controlled by food supply rather than by predators.

Where is the marsupial lion *Thylacoleo carnifex* when we need it? A potential candidate for a novel megacarnivore to control the novel megaherbivores is the much smaller Argentine puma *Puma concolor cabrerae* which instinctively fears humans. Pumas along with wolves and other predators control the elk in North America which has a similar body mass to the Asian sambar, preying mostly on the calves. However they also prey on livestock, especially ‘problem cats’ previously injured by gunshot as livestock are easier prey and could impact severely on some native fauna. There is no direct evidence that pumas can control sambar.

Unlike North America and Europe where top predators such as wolves, lynx, pumas, jaguars and bears are being returned to large wild areas, dingoes have not yet been returned to similar areas in Australia. The main risks are to livestock, threatened native fauna and potentially to people. The sheep industry depends on dingo control, but there are non-lethal means of control including guardian animals such as maremma dogs. Dingoes, along with the entire native predator fauna except eastern quoll, survive on the remote southeast mainland, where they avoid people. This remote area appears to be suitable for rewilding with eastern quolls.

Kangaroo increase in Victoria following the elimination of predators especially dingoes has a parallel in North America where elk in Yellowstone National Park increased after wolves were eliminated in 1926. The devastating effect of overgrazing on the park was apparent by 1929. The gray wolf was listed as endangered under the endangered species act in 1974, and after years of planning, politics and court injunctions, 14 wolves were reintroduced in 1995. They bred rapidly and Yellowstone was famously restored.

Or was it? Everyone seems to agree the rewilding has benefited Yellowstone, but it has reportedly been less successful for aspen forest than first thought as elk numbers, while 40% of what they were before wolves, remain too high for aspen regeneration. Also, the restoration was only partial along the streams. Beavers had disappeared without willows to make dams with, and dams raise the water table for willows in a symbiosis. Without willow cover the streams have become eroded and entrenched, resulting in the water table now being
lower than willow root systems require. Long-term damage to the streams has been caused by nearly 70 years of wolf absence which can be restored only by the construction of dams. 241

There are similar proposals to reintroduce dingoes to parts of Australia such as Sturt National Park. 242 There are also moves to reintroduce dingoes to Wilsons Promontory where they would control native and novel herbivores, allowing regeneration of native grassland. Whether the Australian ecosystems have also sustained long-term damage remains to be seen.

Tim Flannery proposes reintroducing the long extinct Tasmanian devil to mainland Australia where it could help check foxes. 243 Devils are thought to enter fox dens and eat the cubs which may explain why fox introductions have failed in Tasmania. They also prey on possums. The effectiveness of the devil on herbivores versus the fox should be compared before any release. Foxes are effective with brushtail possums on the mainland but in Tasmania the possums irrupt to cause tree decline with less human hunting 244 so they may not be adequately controlled by devils and quolls. Also the devil may not survive in dingo areas.

**Novel ecosystems**

Novel ecosystems are ecosystems that are temporarily or permanently altered by humans. In southeast Australia they are the familiar urban, rural and bushland ecosystems, all with human induced extinctions and/or new arrivals in their flora and fauna. Over time, novel ecosystems may eventually be considered normal or ‘natural’ configurations of nature. The extent to which new species should be accepted as new normal in novel ecosystems depends partly on their impact on existing biodiversity and is subject to debate. 245,246

Novel ecosystems require new management approaches: 247

Many ecosystems are rapidly being transformed into new, non-historical configurations owing to a variety of local and global changes… new systems can arise in the face of primarily biotic change (extinction and/or invasion), primarily abiotic change (e.g. land use or climate change) and a combination of both. Some changes will result in hybrid systems retaining some original characteristics as well as novel elements, whereas larger changes will result in novel systems, which comprise different species, interactions and functions… these novel systems will require significant revision of conservation and restoration norms and practices away from the traditional place-based focus on existing or historical assemblages.

Australian ecosystems are largely hybrid as they contain some original characteristics even if only just a few persistent species and few if any have entirely different species.

European hybrid or novel ecosystems have replaced the Aboriginal novel ecosystem over vast areas. The Aboriginal novel or ‘natural’ ecosystem remains relatively intact in remote areas. It receives attention since it is so diverse, but the European systems should not be overlooked as they are extensive, include all rural land, and support many Australian endemic species.

Every functional ecosystem has its predators and in novel ecosystems some or all are novel predators. The same natural process, predation maintaining diversity, continues to operate but with different players. Just as the dingo after 3500 or more years is considered almost native, the fox may in time be viewed similarly. If immigrant Aboriginal, European, Asian and other humans are now Australian then perhaps the dingo and fox? They are naturalised, integrated components of the Australian ecosystem, but will remain pests of livestock farming unless we go vegan and if rabies arrives they will be of more concern especially the ineradicable fox.

The large majority of the most fox-sensitive fauna group in southeast Australia – ground mammals – has survived the transition from native to novel predators, including over 90% of species on the coastal fall. This is likely due to ancient defensive adaptations to past and present native predators which now serve as effective preadaptations to the fox, and the often...
dense vegetation cover affording protection. The remaining highly fox-sensitive species are now effectively conservation dependent but they occupy a small proportion of the area. Many native fauna populations are suppressed by foxes which increases the risk of local extinction, other risk factors including habitat loss and inappropriate fire regime. The native predators would also suppress populations if they were still there.

After the effective elimination of the original possum predators in the more modified parts of the region by Europeans it was the arrival of the fox which saved the woodlands from possums in those areas. If not for the fox there wouldn’t be woodlands there today. The fox and possum are in ecological balance over extensive areas. Foxes are keystone predators in these woodlands where foxes mean trees. Red gum depends on red fox.

Experience with the predator exclosures and other areas such as Phillip Island shows that fox control when it is effective (and it seldom is) harms the widespread novel bushland ecosystem of southeast Australia where the native ground predators (Aboriginal people, dingoes, quolls, goannas) are missing. Fox control causes herbivore release and imbalance and possible cat or rat release leading to site species loss. Foxes save more species than they cost in this ecosystem. In these situations having no foxes is worse than having foxes.

The dingo fence provides ‘evidence that an alien top predator [dingo] can assume a keystone role and be beneficial for biodiversity conservation’. Experience with predator exclusion shows that another alien, the fox, also plays a keystone role in the widespread situations where the dingo is absent. They both provide an ecosystem service by controlling herbivores.

Here is the simplified structure of a novel ecosystem in general form and an example:

![Trophic structure of novel ecosystem](image)

**Figure 34. Simplified trophic structure of novel ecosystem**
Nitrogen

It is argued by Vic Jurskis and others that the accumulation of nitrogen in soils of dry eucalypt forest in the absence of fire creates a poor root environment and nutritional status for eucalypts which impacts directly on tree health and increases susceptibility to pests and pathogens.\textsuperscript{249,250} According to this model extraordinarily high populations of any folivore are a symptom and not a cause of tree decline, and folivores and trees are coevolved so one can’t cause chronic decline in the other unless humans change the environment. The nitrogen model boldly predicts that trees will die whether banded or not but has some limitations.

It is simplistic to think of possums and their food trees having coevolved in isolation when that coevolution has taken place in the context of an ecosystem containing predators. Throughout their evolutionary history possums have been shaped by predators. There are not two but three players in a more realistic evolutionary model: trees, possums and predators.

According to the nitrogen model coevolved folivores can’t cause chronic decline in trees unless humans change the environment, but a mass predator extinction \textit{is} a human caused change in the environment. Folivores only kill food tree canopies after mass predator loss.

None of the trees appear to be sick prior to being defoliated on the Mornington Peninsula, and when banded they recover unless the band was too late or possums could still access the tree. Uneaten foliage on hanging branches diagnostic of possum damage remains healthy, which is not predicted by the nitrogen model. Many of the defoliated dying trees, while connected or adjacent to dense midstoreys giving possum access, are on sites with root zones too open and mown to be affected by nitrogen, so the model does not explain all losses.

According to the nitrogen model the death of trees with unburnt understoreys is inevitable from the follow-on effects of excess nitrogen whether or not possums kill them first, and ‘possum bands only delay the inevitable’.\textsuperscript{251} In Mount Eliza, while many indigenous eucalypt trees have died from possum defoliation, other causes of mortality are minor. This doesn’t leave room for nitrogen as a major cause and no case of death is attributed to this.\textsuperscript{252} 

While trees in terminal condition don’t survive after banding, trees in critical condition usually recover but some in late critical condition struggle to regrow and retain their foliage in dry conditions. Some of these weakened trees have been killed by drought including trees on mown nature strips that shouldn’t be affected by nitrogen, while others remain in critical condition. They could be interpreted as ‘sick trees’ but since they correlate with the most defoliated trees to start with, late banding is a more likely explanation.

The nitrogen model needs testing by excluding vertebrate folivores from trees in several geographically separate areas of tree decline to see if they recover without fire. This would determine how much of the decline is due to simple folivore pressure. Experience from Cape Otway is that koala banded trees recover without fire.\textsuperscript{253} 

Some equivocal evidence from tree banding in Tasmania is relevant here. In central and southeast Tasmania, brushtail possum densities steadily increased to record levels with reduced hunting following the collapse of the possum fur trade in the early 1980s. Over 400,000 possums were hunted in 1979 before the collapse and fewer than 30,000 possums were hunted in 1993. This was due to change in fashion forced by animal liberationists and the introduction of new fabrics. The possum irruption caused unprecedented defoliation and tree decline in ten eucalypt species, particularly in \textit{Eucalyptus viminalis}, thought to be accelerated on farmland by the use of introduced nitrogen fixing.
clover and superphosphate. The nitrogen model implicates fertilisers and clover along with lack of fire in making foliage more nutritious leading to overpopulation but also predicts that trees will die even if protected. However on one property 13,500 possums were shot over three months leading to start of recovery of the trees that had been significantly defoliated.\textsuperscript{254}

The 2003 Tasmanian state of the environment report refers to a study in which possum guards placed around the base of trees combined with coppicing was effective in improving tree health.\textsuperscript{255} This is not consistent with the nitrogen model as tree decline should have continued. Similarly 23\% of guarded trees improved which is not predicted by the model. The lack of response from the other guarded trees is predicted by the nitrogen model but could have other explanations. Drought was thought to be the primary factor.

Accepting these results, the SoE report found that brushtail possum densities were ‘highest in the low rainfall districts of central and southeast Tasmania. These areas correspond to the main distribution of tree decline in the state. Even though the relationship between tree decline and possum numbers is broad the number of possums may be playing a secondary role to moisture stress in degrading the health of trees already suffering from decline.’\textsuperscript{256} The report does not discuss why previous droughts had not caused mass tree decline.

Drought is now known to damage woody fluid conducting (vascular) tissue in trees due to air entry into the xylem (embolism) which impairs water transport and causes reduced growth and incomplete recovery for 1 to 4 years.\textsuperscript{257} Drought induced embolism is widespread in \textit{Eucalyptus}.\textsuperscript{258} This ‘drought legacy effect’ may render a tree that was already defoliated by possum browsing unable to grow enough new foliage to recover in time to survive. Reduced growth during and after drought in combination with ongoing defoliation may be especially deadly as not enough of what foliage does grow is left uneaten. A reinforcing effect of drought on overbrowsing (an interaction) has been seen on the mainland in Mount Eliza. However, there overbrowsing alone is sufficient to kill trees as there was considerable loss before the Millennium Drought started in 1996 and mortality has continued through La Niñas.

Tasmania is the only state of Australia to allow commercial exploitation of brushtail possums. The industry is now small, with the annual harvest averaging less than 5,500 during 2005–2010. A large number of possums are now taken under crop protection permits, however there was a low period during 1982–1996 between the collapse of the fur trade which precipitated the tree decline and the rise in take under crop protection permits.\textsuperscript{259} Past and present possum predator regimes have not been studied but include hunting by Aboriginal people which was replaced by an export fur trade as early as the 1820s.

While increased nitrogen from lack of fire is presumably making eucalypts more attractive to mammal folivores, low predation appears to be the major factor in mammal induced tree decline. The nitrogen increase is evidently widespread in unburnt dry forests across Australia, but tree canopy loss from mammal folivores is more localised and most consistently linked with low predator pressure. Also, predators can make a kill every night so it is not clear why they wouldn’t keep pace with rising nitrogen and regulate their prey.

It is interesting to note the nitrogen model has fire as the solution to tree decline. Fire also solves the ringtail possum tree decline problem in the predator-prey model. Both models use fire as the solution to tree decline but for different reasons. However the recovery of banded trees is not predicted by the nitrogen model.
Given the major change in predator regimes since the arrival of Europeans, there are likely to be other trophic imbalances besides mammal-mammal imbalances.

Lack of predators may partly or fully explain the noisy miner problem for example. Densities of this aggressive bird have increased in many areas across its wide range. The usual explanation is the opening up of vegetation and fragmentation of woodlands which increases its preferred edge habitat even though such habitats existed before Europeans. It is significant that noisy miner nest predators have declined or are extinct in affected areas.

The large noisy miner population has a long history in the Melbourne area. [Noisy Miner:] By far the commonest and boldest bird in the Australian forests... seen in all places and at all seasons... If the shooter is creeping quietly through the wood for a safe shot, it is ten chances to one that a miner spies him, and warns the prey of his approach; and if by chance a snake or stump-lizard shows a head, a congregation of miners will soon gather round it, and spread the news through the whole neighbourhood... They are common in all parts of the bush throughout the year.

Wheelwright is usually thought to be describing the relatively intact fauna of 1850s Melbourne so were his common noisy miners natural? If so we should get over it and accept this bully. There was little or no clearing where he roamed and many areas were naturally open (see Figure 27). But he was there 18–22 years after the settlement of Melbourne in 1835 and notably the major nest predators spot-tailed quoll and lace monitor were rare or restricted.

Wheelwright described the ‘tiger-cat’ as ‘rather a rare animal... sparingly dispersed over the thick bush... rarely seen, although I have oftener killed them by day than night.’ Meanwhile the ‘guano’ was a ‘repulsive-looking reptile’ which ‘frequents gullies and ranges where the timber is high, and the localities wild and unfrequented... I have seen them in the Dandenong ranges, and I believe they are very common in the high timber on the Gipps Land Road.’

The quoll was widespread but midstorey dependent while the lace monitor is likely to have hunted in the old growth woodlands and forests of eastern Melbourne, requiring the large trees with hollow shelters, often river red gums or manna gums. With treeless grassland west of Melbourne it was on the edge of range. Aboriginal people may have eliminated the giant monitor lizard Megalania but they didn’t and possibly couldn’t eliminate the smaller semi-arboreal lizard so they coexisted in predator-prey balance for some 45–50,000 years. Dingoes and eagles also preyed on goannas but did not eliminate them. The goanna and quoll were persecuted by Europeans and were among the first fauna to go extinct in the area. Wheelwright may have been there after the miner’s ecological release.

Lace monitor is absent from Tasmania where other nest predators prey on noisy miner. The nest robber spot-tailed quoll is likely to be a major predator. The bird has many potential nest predators, with 19 such species including goanna recorded in Queensland.

While chasing away small birds including the honeyeaters, at least noisy miners continue to keep tree canopies healthy by preying on insects that can devastate eucalypts. The noisy miner replaces the combined effort of several honeyeaters in this ecological function. In contrast the also aggressive bell miner is involved in bell miner associated decline (BMAD).

The slow decline of old growth coast banksia Banksia integrifolia woodland due to native borers (longicorn beetle larvae) in Seaford and the slow decline of black sheoak Allocasuarina littoralis trees due to another native borer in Mount Eliza may be related to the loss of predatory glossy black cockatoos and/or parasitoid wasps.
**Trophic model**

The predator-prey or trophic model of ecosystem function consists of multiple site-specific food chains interlinked in a food web. Based on predation, an essential ecological process, it is predictive and effective as a management tool. The trophic model is used in various forms to understand and manage fisheries\textsuperscript{264,265} and applies equally well on land.

The trophic model is based on the trophic structure of an ecosystem and can be quantified in various ways including energy flow, population dynamics and cost estimation.

The ‘inclusion of processes represented mathematically as density-dependent regulation of either consumer uptake or mortality rates is necessary for the generation of realistic top-down cascades in simple food chain models. Realistically modelled ‘bottom-up’ cascades, caused by changing nutrient input, are also dependent on the inclusion of density dependence’.\textsuperscript{266}

The model can be applied to understand healthy systems, adjust predator and herbivore pressure in modified systems, and develop appropriate policies and interventions. The example in *Common ringtail possum* is an application of the model to stop tree decline. Both interventions derived from the model, possum banding and midstorey thinning, work.

Due to human influence many novel ecosystems lack top predators. For example in Mount Eliza bushland the fox is the surrogate top predator in a diverse novel ecosystem that supports most of the original species. It alone controls possums and so uniquely protects the tree canopy and dependent species. The model indicates that fox control is counterproductive here.

The trophic model is useful in understanding, facilitating and intervening in trophic interactions to optimise Australian biodiversity in present-day landscapes and to protect vegetation, soils and streams from the adverse effects of herbivore imbalance.
Research

While there is considerable research in autecology, the study of single species, there are many research needs and opportunities in synecology or community ecology which is the study of species in communities including their trophic ecology.

Understanding of novel ecosystem management is increasing as experience is obtained and theoretical and practical questions are explored through trials and experiments. Conservation biology becomes more complex, interesting and effective.

Comparative studies of predator, prey/herbivore and vegetation/food resource levels within predator exclosures relative to open systems would be informative. The reintroduction of native predators and dingoes into predator exclosures should be monitored.

Future predator exclosures should obtain baseline monitoring data before any change on the ground. Relevant variables to measure include predator, omnivore and herbivore density and biomass by species, and plant cover and biomass by species and vegetation layer. Data should be collected from both inside and outside planned exclosures.

The trophic structure and function of Victoria’s 28 bioregions and Tasmania’s 9 bioregions warrant study. Each bioregion has its own characteristics based on its component species. What controls the population size of each major herbivore, omnivore and predator? What do they eat and not eat? The Aboriginal and European systems can be compared. Research on bioregional ecology has scientific interest and many applications.

The food web of the Mallee is interesting but not well understood for example. What is the role of the fox where there are numerous native and novel herbivores and omnivores and listed threatened fauna are recorded in <0.5% of the fox diet? What controls brushtail possums in yellow gum woodland in the Little Desert and in river red gum woodland along the Wimmera River? Why are foxes ‘positively correlated with malleefowl conservation’?

Foxes prey on malleefowl Leipoa ocellata but they appear to be in widespread predator-prey balance. Malleefowl are highly fecund. A female malleefowl may produce some 400 eggs in her lifetime of which only two make it to the adult stage in a stable population. The other >99% either fail to hatch (some 20%) or the birds die young as eggs or immature birds mainly from predators or heat stress, factors that have been operating for millions of years.

Does the link between foxes and malleefowl reflect fewer dingoes as they kill foxes and could be more efficient predators of malleefowl? Or do foxes suppress cats? Do foxes suppress rabbits and goats which compete for food with malleefowl? Fortunately the malleefowl has effective preadaptations against the fox – it has been dealing with ground predators for millions of years. The giant malleefowl Leipoa gallinacea was not so fortunate – it didn’t survive Aboriginal people possibly due to its larger size and larger nest mound. It was one of many large megapodes sent extinct by humans in the Australia–Pacific region.

In relatively ‘natural’ ecosystems such as in East Gippsland, herbivores under natural predator pressure occupy territories large enough to sustain both themselves and their food supply. In the event of a mass predator extinction such as on the Mornington Peninsula, we may predict that individual herbivores experience more aggressive encounters with other now surviving individuals and that territories shrink in response to below the minimum area needed to sustain the food supply, which leads to catastrophic loss. Hence 16 possums per hectare in Mount Eliza until their population crashes along with the trees. A theoretical return of predators may lead to an expansion in home ranges back up to sustainable sizes. A positive correlation between predator pressure and home range size is a testable hypothesis.
Conclusion

We have briefly overviewed the terrestrial predator-prey ecology of southeast Australia at the high trophic levels and explored the interface between flora and fauna in the region.

As elsewhere, most ecosystems in the region require vertebrate predators to control vertebrate herbivores for ecosystem structure and function. Predator pressure is basic to these systems.

The evidence indicates the real ecology of southeast Australia is not what we thought. A hidden bias in conservation management is revealed by experience with predator exclosures. Major herbivore imbalances inside exclosures show that novel ground predators normally control native and novel herbivores in more human-modified areas due to the widespread loss of native predators. Together with any remaining native predators they are essential in order to keep novel bushland ecosystems relatively healthy and balanced.

The dingo/dog is the partial replacement top predator for humans, thylacines and devils but is now rare or absent over large areas. The fox and cat are widespread partial replacement mesopredators for quolls, goannas, pythons and other predators. However the novel predators compete with or prey on several native predators, and the fox without its top predator dingo appears to undergo mesopredator release which increases its impact on threatened fauna.

Where dingoes/dogs are eliminated or kept at low levels, foxes and cats are major ground predators. The fox is a keystone predator in these widespread situations, benefiting many native species by protecting trees and habitat. Rabbits for example are limited by these predators and viral diseases rather than food supply, otherwise the land would be stripped almost bare, which is not the case. The novel predators are informal biological control agents.

Whether novel predators can perform this role effectively, and whether their beneficial control of herbivores outweighs their toll on sensitive native prey populations, depends on the site.

With eighteen native and eight novel mammal herbivores in the region, each predator has preferred prey based on size and availability. Dingoes suppress foxes which may suppress cats. Many or most of the flora and fauna in these novel ecosystems are Australian endemics. These contemporary land systems need sympathetic protection and management using an adaptive, evidence-based approach. Otherwise forget about having red gums.

Predator pressure on folivores turns out to be a higher priority than the elimination of novel predators where canopies are at risk to folivores. Here in particular the ‘alien is bad’ approach is illogical and counterproductive if there are no native predators. It can also be wasteful of resources and promoted by people who believe they are ‘saving wildlife’. Indeed the extent to which edible eucalypts such as river red gum survive over large areas may indicate the non-existent, temporary, ineffective or localised effect of fox control.

A natural ecological logic or trophic paradigm of ecology in which predators control herbivores is most appropriate. The fantasy school of ecology in which the alien predators must be killed so the native fauna can live and reproduce in peace only means ecological damage if there are no other predators. That’s not the way ecology works and never has been. We have to manage the actual ecosystem, not an imagined predator-free system that never existed. The antipredator paradigm is in large part pseudo conservation based on a misunderstanding of ecology and is generally counterproductive to conservation.

Ideology, silo mentality and vested interest should not override conservation biology.
Predator exclosures breed threatened mammals but should not be at the expense of the site ecosystem unless the purpose is an open range zoo rather than ecological restoration. The exclosures become sacrificial sites for the conservation of a few species. They are too small to support viable fauna populations due to inbreeding caused by small population size and require genetic input from outside, making them zoo-like. There has been a tendency in mammal conservation to pick the best remnant patch of nature in a district and then accidentally ruin it. In order to maintain site vegetation and biodiversity, herbivores need control or elimination as well as their predators.

Since the net ecological benefit of removing all predators from ecosystems is doubtful or not there, animal rights and welfare issues relating to foxes are more prominent.

Maintaining a balance between predators, herbivores and habitats for all species in southeast Australia involves managing predator and herbivore pressure with sound policies and interventions. Indeed this applies to ecological land management worldwide.

The trophic model is useful in understanding, facilitating and intervening in trophic interactions to optimise Australian biodiversity in present-day landscapes. This may include retaining novel replacement species on a site basis which can be temporary or permanent depending on whether the corresponding natives can recover. This is part of a pragmatic or deep conservation approach which extends from retaining foxes for trees to retaining pines for cockatoos, onion grass for corellas, or blackberry cover for scrub birds. Purist ideology in which all novel species must be eliminated is not very helpful or practical in novel ecosystems. The aim is to ease the transition of Australian biodiversity to novel ecosystems.

Given our improved understanding of the predator-prey ecology of southeast Australia based on experience with predator exclosures and the possum and koala banding of trees, any further loss of tree canopy to herbivores from now on can be seen as management failure.

The following management approaches or guidelines are aimed at maintaining trophic diversity and an ecological balance between predators, herbivores and their shared habitat:

- ‘Read the bush’ by observing levels of browsing and grazing in all vegetation layers and looking for live herbivores and predators as well as their tracks, scats and remains.

- Analyse the trophic structure of site and bioregional ecosystems. Determine what is controlling the population size of each major species.

- Be aware of the complexity of predator ecology and pest animal control, anticipating and looking for ecosystem responses including change in herbivore pressure.

- Manage rather than necessarily eliminate novel predators where they control herbivores and the corresponding native predators are functionally extinct.

- Avoid fox control in novel bushland ecosystems that otherwise lack vertebrate ground predators due to the adverse effects of herbivore and cat release, except for below.

- Consider strategic predator control where populations of listed threatened fauna are suppressed by predators, in combination with monitoring of canopy health, sensitive plant populations and other habitat indicators.
• Consider means of reducing overabundant herbivores other than by predators, including contraception, culling, disease or habitat modification using control burns etc.

• Consider culling of herbivores as a management measure in significant areas.

• Protect large trees from overbrowsing, especially in prominent or strategic locations.

• Avoid installing nest boxes for possums where they may threaten canopy trees.

• Avoid release of rescued or trapped possums into bushland where habitats are already saturated with possums, as it is futile and increases animal suffering.

• Review the protected status of possums in designated areas of possum induced tree decline in order to protect trees and biodiversity.

• Manage woodlands back towards their original relatively open structure through biomass reduction to prevent ringtail possum overpopulation.

• Prevent herbivore imbalance in predator exclosures by reintroducing native predators, by directly controlling herbivores, or by creating exclosures in revegetation where it is not easy to damage the site ecosystem.

• Support well planned and viable reintroductions of native predators.

• Take measures to protect native predators, to allow these keystone species to continue in the vital ecological role of controlling herbivore pressure in natural areas.

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**Paradigm:**
Trophic paradigm of ecology
Every ecosystem has its predators, make them native where possible

**Management model:**
Trophic model of ecosystem function

**Mission:**
Optimise Australian biodiversity in Australian novel ecosystems

**Think trophically, act locally**

**Good luck and good management!**
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References


Morgan J 1980. The life and adventures of William Buckley, thirty-two years a wanderer amongst the Aborigines of the unexplored country round Port Phillip, now the province of Victoria. Australian National University Press, Canberra.


Saltré F, Rodríguez-Rey M, Brook BW, Johnson CN; Turney CSM, Alroy J, Cooper A, Beeton N, Bird MI, Fordham DA, Gillespie R, Herrando-Pérez S, Jacobs, Z, Miller GH, Nogués-Bravo D,


Smythe GD 1841. Survey of the coast of Port Phillip from the mouth of Tangenong Creek to Arthur’s Seat. George D Smythe, Contract Surveyor.


# Appendix 1. Mammal herbivores of southeast Australia

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<th>Common name</th>
<th>Scientific name</th>
<th>Family</th>
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<td><strong>Native species:</strong></td>
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<td><em>Osphranter rufus</em></td>
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<td>Black wallaby</td>
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<td><em>Petrogale penicillata</em></td>
<td>Macropodidae</td>
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<td><em>Oryctolagus cuniculus</em></td>
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V Listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999*

**Notes:**
- some omnivores such as common brushtail possum are primarily herbivorous and close to being herbivores
- little red flying-fox eats lerps at times and may be considered an omnivore.
Appendix 2. Media reports

Ringtail possum associated decline (RPAD):

- Trail of destruction: group wants to get possums out of trees
  *Mornington Peninsula Leader*, 16/4/13, p 3
  First media alert, Mount Eliza Association for Environmental Care (MEAFEC)
  [leader.newspaperdirect.com/epaper/viewer.aspx](http://leader.newspaperdirect.com/epaper/viewer.aspx)
or web search headline

- How to limit marsupials’ toll
  *Mornington Peninsula Leader*, 30/4/13, p 20
  Sensational headline and other inaccuracies in above report by newspaper
  clarified by MEAFEC and further advice is provided:
  – thousands of trees are affected not 20 which are priority roadside trees,
  – aim is balanced ecology with sustainable number of possums in trees not ‘out of trees’,
  – tips on protecting trees,
  – possum band is cheaper than removing a dead tree
  No link available

- Fox seen as answer to possum problem
  *Mornington News*, 17/11/15, p 5
  Sensational headline by newspaper, appropriate headline is ‘Understorey reduction seen as answer to possum problem’ since fox is only part of the answer

- Eucalypt dieback ‘not just possums’
  *Mornington News*, 24/11/15, p 5
  Deniers refute ringtail possum is the primary cause of tree decline and fox has any ecological role or value

- Ringtail possums and tree decline
  *Mornington News*, 1/12/15, p 12
  Response to deniers, summary of situation, edited by newspaper, follows next page
  No link available
Ringtail possums and tree decline

OPINION

By Dr Jeff Yugovic

INDIGENOUS eucalypt trees are undergoing a massive decline from Mt Eliza to Mt Martha and beyond with the problem was first noticed by members of Mt Eliza Association For Environmental Care.

Ringtail possums overbrowsing “appears to be the main causal factor”, according to a 2014 study by Ecology Australia commissioned by Mornington Peninsula Shire to investigate the problem in Mt Eliza. The study concluded that the prognosis for remaining eucalypts was “extremely poor”.

Study findings were consistent with my observations. Possum damage is easily diagnosed and the recovery of trees after possum banding has proved that ringtails are killing the trees. Other forms of tree mortality are minor.

The tree decline is linked to dense, scrubby understoreys in which the ringtails evade their only remaining predator, the fox on the ground below. The major native predators of ringtail possum are locally extinct including aerial and arboreal predators, which is why there is a ringtail overpopulation. The problem is due to habitat alteration rather than habitat loss.

Recently my research has received attention in this newspaper (“Fox seen as answer to possum problem”, The News, 17/11/15), which caused some controversy. While MEAFEC agrees with EA and me that ringtails are the primary cause of decline, local wildlife experts Mal Legg, Hans Brunner and Craig Thomson refute this (“Eucalypt dieback not just possums”, The News, 24/11/15).

They don’t live in the affected area or understand the problem. They say that tree decline has many causes, that it is multi-factorial. The EA study and my research have found that the multi-factors are essentially dandy possum, mummy possum and baby possum. Not to diagnose the problem correctly is to delay action, which could cost all of the remaining trees.

The answer to the tree decline is simple and effective – thin the understorey and the tree decline will stop. Possums will be back in balance. Why? Because there will be less habitat for possums and more possums taken on the ground by foxes, their only remaining predator. Culling is not an option, it is impractical to reintroduce the native predators, and we can’t band all the trees.

Understorey reduction as a management option is identified by Ecology Australia. Its report suggests this will reduce ringtail habitat suitability and increase the risk of predation. It is fully supported by MEAFEC.

Contrary to some claims, this is not a radical solution. Smythe’s 1841 survey showed that understoreys were mostly open at the time of European settlement so the currently dense understoreys are modern. The practical solution is to restore the open understoreys that previously existed. It doesn’t require any more foxes than already exist. Foxes are everywhere and have proved impossible to eliminate. They partly replace the dingoes. Yes, control foxes for fauna on the state threatened list, but there are none in the affected area.

Ecological thinning and burning will also greatly reduce the fire hazard in the affected area. As a CFA member I know that fuel loads are very high and there is the potential for very dangerous fires in the area. The possum solution will also address this fire danger in a major way.

Practical tips on diagnosing possum damage and installing possum bands are in the online discussion paper www.sprffa.org/do-ecosystem-systems-need-top-predators.html I would suggest that people download and read this so we can save the remaining trees, with possums in balance and fire hazards reduced.

• Jeff Yugovic has an honours degree in botany and genetics from the University of Melbourne, a PhD in ecology from Monash University, and is a senior consultant ecologist with Biosis Pty Ltd.
Appendix 3. Mornington Peninsula context

Role of predators

Rabbits were in Mount Eliza Berinjup and surrounds when it was rural land prior to suburban development from the 1950s. They went locally extinct in gardens and bushland reserves due to suburban high predator pressure: background fox pressure plus domestic cat and dog pressure. Mount Eliza is better off without this herbivore though exotic grass cover is higher. Without these novel predators rabbits would recolonise Mount Eliza and the Shire and residents would need to build rabbit fences around many sites including vegetable gardens.

Lack of predator pressure on possums, rats and possibly noisy miners in recent years has led to net loss of flora and fauna. The site extinction rate exceeds the site colonisation rate due to out-of-balance species and habitat isolation. Indigenous trees killed by possums are generally not replaced. Replacing trees in reserves via natural regeneration is challenging, requiring biomass reduction for light and surviving adjacent tree seed sources. Where no trees survive, site reintroduction via planting or direct seeding may be appropriate. But there is little point in reintroducing sensitive species unless plants are protected or herbivore pressure is reduced.

Predator control

Mornington Peninsula Shire has a commitment to biodiversity protection and enhancement which includes pest animal management. A cat curfew since 1997 requiring cats to be confined to the owner’s property means they are mostly kept indoors in many areas. Intensive fox and cat control has also been undertaken since 2007 in certain high quality bushland reserves which is about 5% of council reserves. These include two in Mount Eliza where fox control (sensibly) ceased in 2016. Control programs were extended to national parks in 2011. By comparison with other areas the effects of these programs and policies can be assessed.

Frankston South to Mount Martha is the epicentre of possum induced tree decline on the Peninsula. Bushland reserves have no listed threatened fauna and possums and swamp rats are the only native mammals apart from bats and sugar gliders. Cats are largely absent due to the curfew and foxes and cats are controlled in some reserves. These remarkable predator free areas have lost or are losing their canopy to possums and orchids to rats. Further south, on the Nepean Peninsula coast tea-tree scrub is also dependent on predators controlling ringtail possums. It is counterproductive to eliminate the only possum predators where possums are killing tree canopies which impacts on dependent species including sugar glider.

Climate change

It is perverse to rely on global warming to solve an environmental problem and in any case the predicted heat waves won’t happen in time to save the remaining woodlands from possum induced tree decline on the northern Mornington Peninsula. Biomass reduction is needed.

Fire

Could fire reduce midstoreys enough to keep ringtail possums in balance with the canopy? Probably but the effect of fire is temporary. A shrubby understorey redevelops within 20 years so it would take a high fire frequency which may not be practicable or desirable, although perhaps the Aboriginal people did burn at this average site fire frequency. The relative contribution of fire and black wallaby in controlling shrub cover and thus ringtail shelter in the Aboriginal ecosystem is not clear as both factors push in the same direction. In Mount Eliza extensive fire is not known in living memory and not since residential development. However, even in this absence of fire there was no significant shrub build up, and thus ringtail overpopulation and canopy loss, until after the extinction of black wallabies in the 80s suggesting that wallaby browsing was a major factor.
Appendix 4. References by section

Introduction
1 McGraw-Hill Concise Encyclopedia of Bioscience 2002
2 Elton 1927
3 Hairston, Smith, Slobodkin 1960
4 Paine 1969
5 Wikipedia 2017b
6 Stolzenburg 2008
7 Terborgh, Estes 2010
8 Ripple et al. 2014
9 Danell et al. 2006
10 Terborgh, Estes 2010
11 Brett, Goldman 1996
12 Strong 1992
13 Estes et al. 2011
14 University of Michigan 2005
15 Caughley 1981
16 Prevedello et al. 2013
17 Turkington 2009
18 Glen, Dickman 2014

Native predators
19 DSE 2013
20 Gammage 2011
21 Morgan 1980
22 Smith 2015
23 Menkhorst 1995
24 Johnson 2015
25 Prugh et al. 2009
26 Roberts et al. 2001
27 Miller et al. 2005
28 Saltre et al. 2016
29 Wroe et al. 2013
30 Westaway et al. 2017
31 Wikipedia 2017a
32 Wikipedia 2017c
33 Wheelwright 1861
34 Andrew et al. 1984
35 Weavers 1989
36 Jessop et al. 2010

Novel predators
37 Smith, Savolainen 2015
38 Menkhorst 1995
39 Jones 1990
40 Stephens D 2011
41 Menkhorst 1995
42 White et al. 2006
43 Davis et al. 2015
44 Johnson 2015
45 Banks et al. 2000
46 Saunders et al. 2010
47 Short et al. 2002
48 Menkhorst 1995
49 Agriculture Victoria 2016
50 WPSA 2007
51 Brian Coman, zoologist, pers. comm.
52 Menkhorst 1995
53 Barratt 1997
Native herbivore imbalance

59 Darcy Duggan, ecologist, pers. comm.
60 Coulson 2007
61 Coulson 2001
62 Coulson 2007
63 McIntyre et al. 2010
64 Manning et al. 2011
65 Shorthouse et al. 2012
66 Krebs et al. 1969
67 Ostfeld 1994

Case studies – species

68 Coulson 2001
69 DELWP 2017e
70 DSEWPaC 2012
71 DELWP 2017d
72 Grigg 2002
73 Wilson, Edwards 2008
74 Bennett 1995b
75 Coulson 2001
76 DELWP 2017e
77 Bennett 1995a
78 Bennett 1995a
79 Barker, Caughley 1992
80 Banks et al. 2000
81 Coulson 2001
82 Coulson 2007
83 McIntyre et al. 2010
84 Howland, Driscoll 2016
85 EPSDD 2016
86 The Canberra Times 23 April 2016
87 Winnard, Coulson 2008
88 DELWP 2017e
89 Bennett 1995c
90 Coulson 2001
91 Cheal 1986
92 Sluiter et al. 1997
93 Mildura Independent 7 June 2016
94 DELWP 2017e
95 Dexter et al. 2013
96 Menkhorst 1995
97 DoEE 2017a
98 Menkhorst 2008
99 Gibson, Thomas 2012
100 Sue McIntyre, ecologist, pers. comm.
101 Martin 1985a
102 Martin 1985b
103 Menkhorst 2008
104 Todd et al. 2008
105 Wallis 2013
106 Menkhorst 2004
107 Menkhorst 2008
108 The Age 4 March 2015
Case studies – sites
176 GSV 1967
177 DSE 2003
178 Wheelwright 1861
179 Malcolm Legg, zoologist, pers. comm.
180 Triggs 1996
181 Salo et al. 2007
182 Banks 1999
183 Banks et al. 2000
184 Menkhorst 2010
185 Yugovic 1998
186 Stolzenburg 2008
187 Ripple et al. 2014
188 Morris, Letnic 2017
189 Menkhorst, Morison 2012
190 Salo et al. 2007
191 Ritchie, Johnson 2009
192 Johnson et al. 2007
193 Colman et al. 2014
194 Soulé in Stolzenburg 2008
195 Letnic et al. 2012
196 Letnic et al. 2009
197 Risbey et al. 2000
198 Robley et al. 2004
200 Allen et al. 2011
201 Allen 2015
202 Colman et al. 2015
203 ABC News 28 February 2017
204 Hanna, Cardillo 2014
205 Doody et al. 2015
206 Doherty et al. 2016
207 Salo et al. 2007
208 Johnson, Isaac 2009
209 Henry 1995
210 Seebeck 1995
211 Kinnear at al. 2002
212 Davis et al. 2015
213 Brunner et al. 1976
214 Walsh et al. 2012

Discussion
181 Terborgh, Estes 2010
182 Laundré et al. 2010
183 Roger Bilney, zoologist, pers. comm.
184 Triggs 1996
185 Salo et al. 2007
186 Banks 1999
187 Banks et al. 2000
188 Menkhorst 2010
189 Yugovic 1998
190 Stolzenburg 2008
191 Ripple et al. 2014
192 Morris, Letnic 2017
193 Menkhorst, Morison 2012
194 Salo et al. 2007
195 Ritchie, Johnson 2009
196 Johnson et al. 2007
197 Colman et al. 2014
198 Soulé in Stolzenburg 2008
199 Letnic et al. 2012
200 Letnic et al. 2009
201 Risbey et al. 2000
202 Robley et al. 2004
203 Gordon et al. 2016
204 Allen et al. 2011
205 Allen 2015
206 Colman et al. 2015
207 ABC News 28 February 2017
208 Hanna, Cardillo 2014
209 Doody et al. 2015
210 Doherty et al. 2016
211 Salo et al. 2007
212 Johnson, Isaac 2009
213 Henry 1995
214 Seebeck 1995
215 Kinnear at al. 2002
216 Davis et al. 2015
217 Brunner et al. 1976
218 Walsh et al. 2012

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